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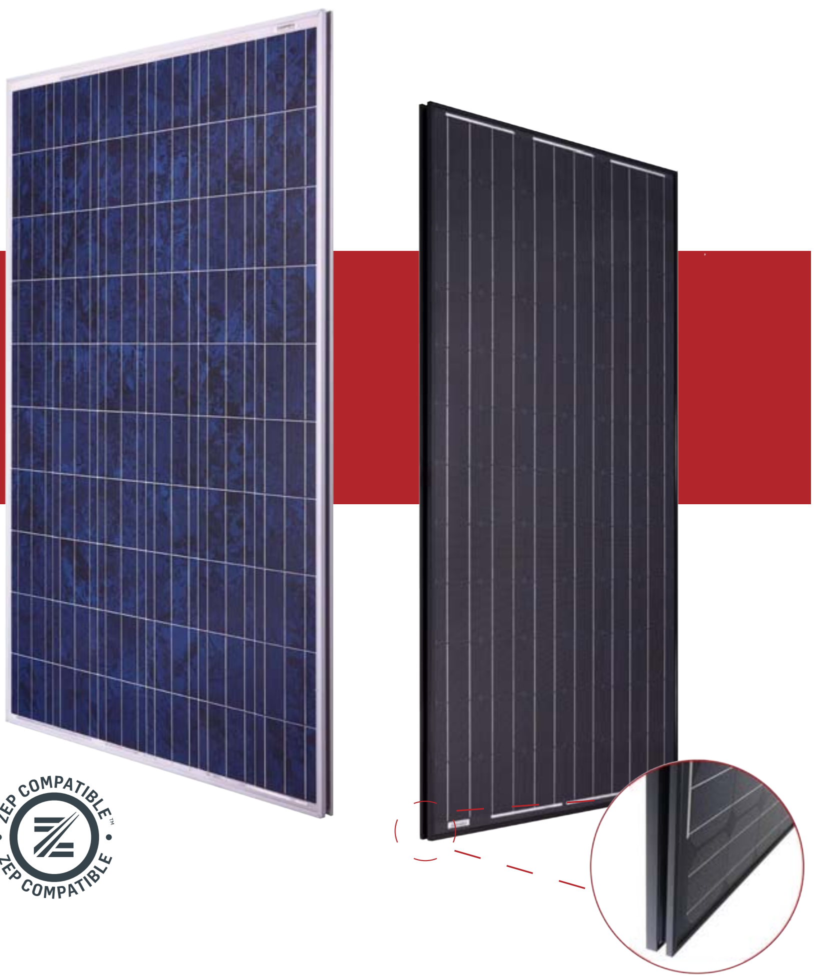

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On the Cover

Jerry Ostermeier of Alternative Power & Machine with a three-nozzle microhydro turbine.

Photo: Shawn Schreiner

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These pages, left to right: Josh Kordecky/Alpenglow Solar; MidNite Solar; Ted Dillard; Harry Martin; SunPower; SunWater Power Systems

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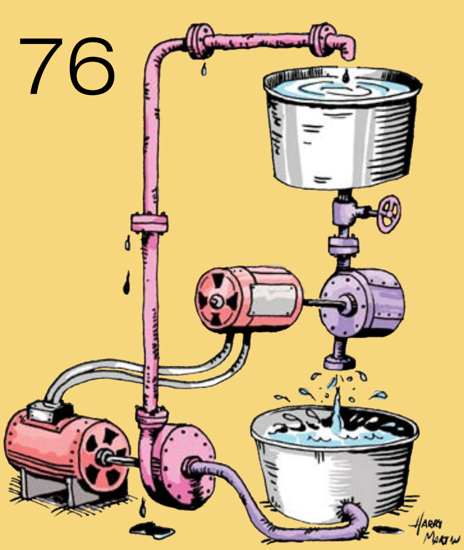

More Features

In Back

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Sizzling *Sustainability*

In this era of increasing utility rates, economic and social uncertainty, and *decreasing* renewable energy (RE) costs, why don't more of us have RE systems?

While dirty energy subsidies, corporate meddling, and foreign competition are not helping—perhaps we can make progress among ourselves by examining why the RE industry has a hard time selling systems. You could also ask yourself why it's so hard to pull out your checkbook. After all, you pull it out regularly to buy all kinds of things that you value.

We often overlook a key reason that we don't see RE systems in every block in America—the RE industry hasn't quite figured out what makes American buyers tick.

The tobacco industry is widely successful selling cigarettes—a product that causes illness and death! That industry maintains its profitability in the face of very high taxes, public campaigns against their products, and a general social knowledge that cigarettes are "bad for you." Americans spend money on a wide variety of things that "don't make sense," but the industries behind those products don't let that idea stop them. If they can make a go of promoting those products, there's no reason why the RE industry, which is promoting clean energy solutions—something good for us and the planet—can't build on their products' popularity.

The iconic Marlboro man is said to be one of the most brilliant advertising campaigns of all time. How will the RE industry make its impact on marketing clean energy to the masses?

There are a variety of motivations behind our purchases—including economic, environmental, and product reliability. Perhaps underappreciated is how many of our buying decisions are made because we *feel* good about the stuff we buy. One aspect of this is what I call "the cool factor," which accounts for a *lot* of buying motivation in modern America.

Too often we get hung up on justifying the "payback," or engrossed in technical talk. If we frame the discussion in these ways, we often shoot ourselves in the foot, by losing sight of the fabulous and saleable nature of products that provide clean energy for the long haul.

Instead of trying impress our motivations, justifications, and points of view, perhaps the RE industry should consider exploring what really makes consumers buy what they buy, so we can "sell the sizzle" of sustainability. And each of us with an RE system can become an ambassador, sharing our excitement with neighbors, friends, and family.

—Ian Woofenden, for the *Home Power* crew

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You can never have an impact on society if you have not changed yourself.

—Nelson Mandela

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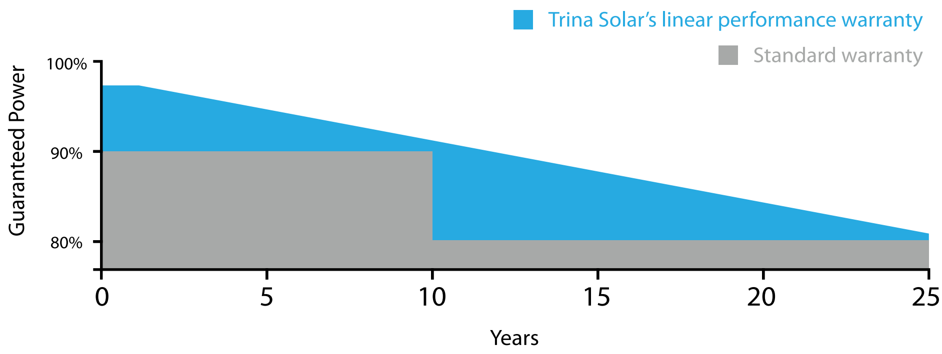

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The power behind the panel

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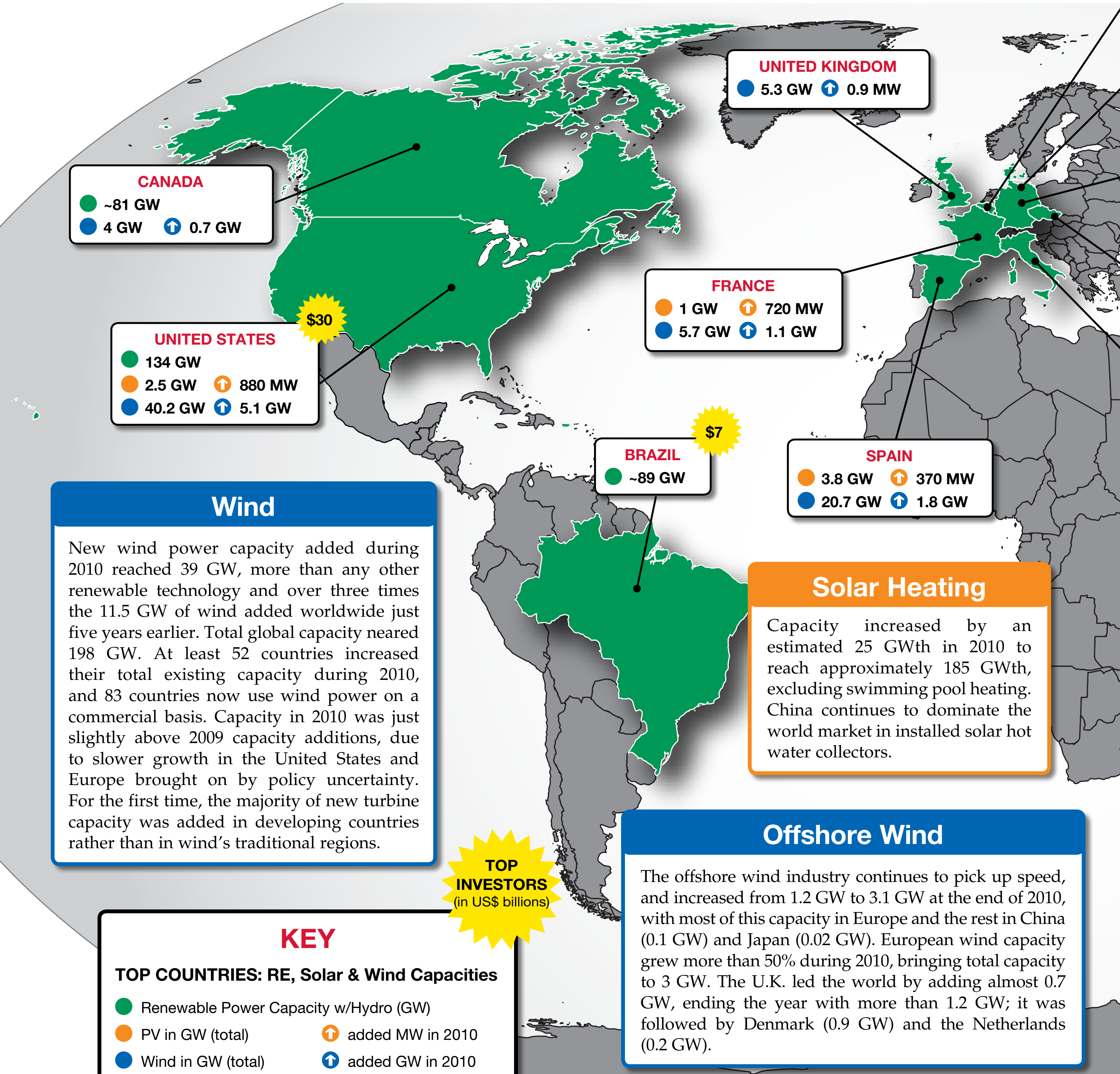
Global RE Overview

Changes in renewable energy markets, investments, industries, and policies have been so rapid in recent years that perceptions of the status of RE can lag years behind the reality. The *Renewables 2011 Global Status Report* (produced by the Worldwatch Institute and REN21) provides an overview of RE worldwide as of early 2011. The report shows that the RE sector continued to grow, despite continuing economic recession, incentive cuts, and low natural gas prices. Here are highlights from the report.



Wind

New wind power capacity added during 2010 reached 39 GW, more than any other renewable technology and over three times the 11.5 GW of wind added worldwide just five years earlier. Total global capacity neared 198 GW. At least 52 countries increased their total existing capacity during 2010, and 83 countries now use wind power on a commercial basis. Capacity in 2010 was just slightly above 2009 capacity additions, due to slower growth in the United States and Europe brought on by policy uncertainty. For the first time, the majority of new turbine capacity was added in developing countries rather than in wind's traditional regions.

Solar Heating

Capacity increased by an estimated 25 GWth in 2010 to reach approximately 185 GWth, excluding swimming pool heating. China continues to dominate the world market in installed solar hot water collectors.

Offshore Wind

The offshore wind industry continues to pick up speed, and increased from 1.2 GW to 3.1 GW at the end of 2010, with most of this capacity in Europe and the rest in China (0.1 GW) and Japan (0.02 GW). European wind capacity grew more than 50% during 2010, bringing total capacity to 3 GW. The U.K. led the world by adding almost 0.7 GW, ending the year with more than 1.2 GW; it was followed by Denmark (0.9 GW) and the Netherlands (0.2 GW).

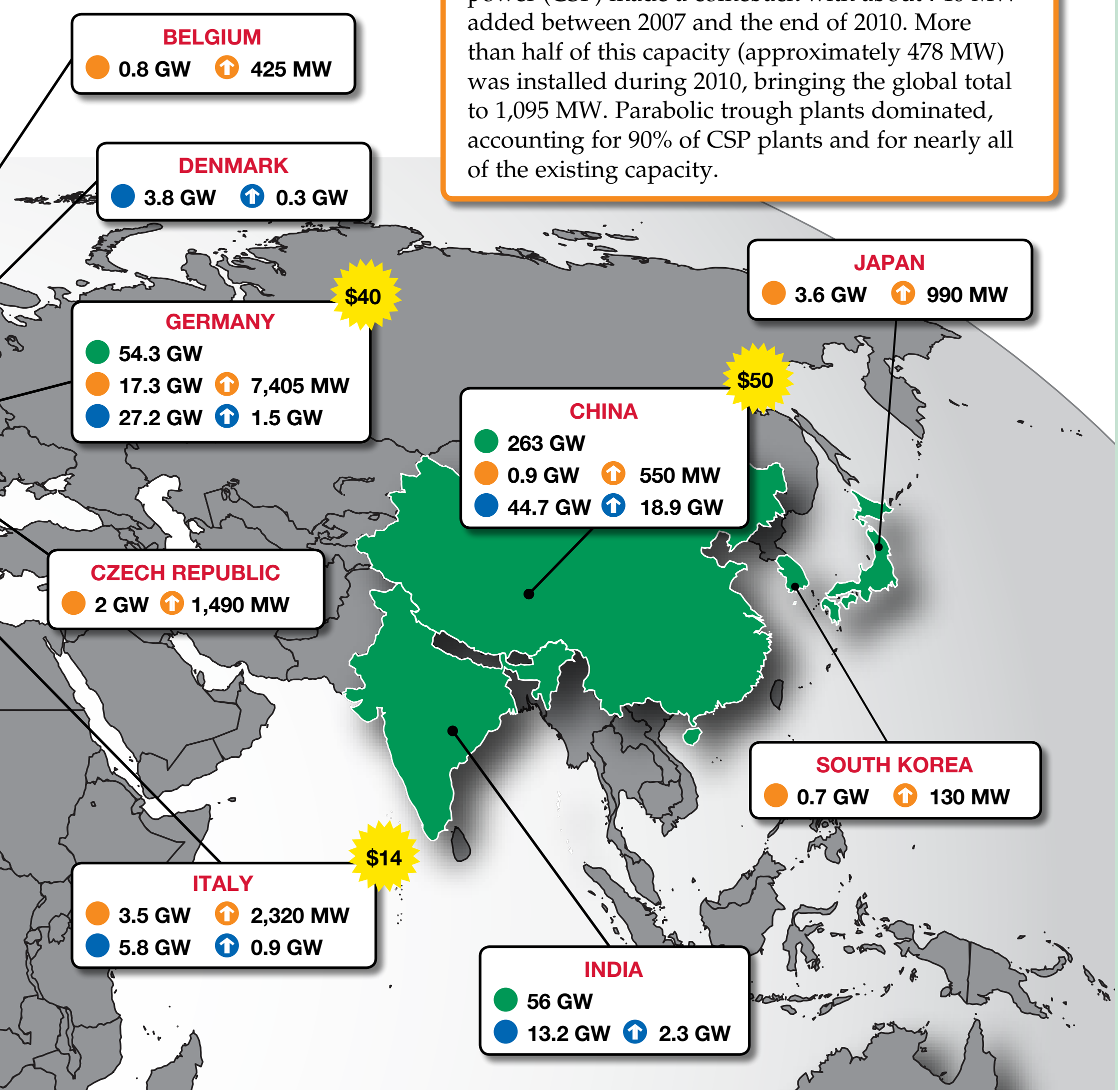
KEY

TOP COUNTRIES: RE, Solar & Wind Capacities

- Renewable Power Capacity w/Hydro (GW)
- PV in GW (total)
- Wind in GW (total)
- added MW in 2010
- added GW in 2010

Solar Thermal

After years of inactivity, concentrating solar thermal power (CSP) made a comeback with about 740 MW added between 2007 and the end of 2010. More than half of this capacity (approximately 478 MW) was installed during 2010, bringing the global total to 1,095 MW. Parabolic trough plants dominated, accounting for 90% of CSP plants and for nearly all of the existing capacity.



Photovoltaics

Thanks to government incentive programs and the continued fall in PV module prices, an estimated 17 GW of PV capacity was added worldwide (compared with just under 7.3 GW in 2009). That brought the global total to about 40 GW—more than seven times the capacity in place five years earlier. The EU dominated the global PV market, led by Italy and Germany, which installed more PV in 2010 than the entire world did the previous year. More than 5,000 utility-scale PV plants accounted for almost 25% of total global PV capacity, with 9.7 GW of capacity by the end of 2010—an increase of more than 3 GW during the year. The EU continued to lead with 84% of the global total, with Germany accounting for about one-third of global additions. By the end of 2010, Spain had 32% of total installed utility-scale capacity, followed by Germany (26%), Italy (16%), the United States (7%), and the Czech Republic (6%).

WORLDWIDE

Net metering policies exist in at least 14 countries, including Italy, Japan, Jordan, and Mexico, and in almost all U.S. states.

World Stats

PV Capacity—40 GW
Solar Thermal Power (CSP) —1.1 GW
Wind Power Capacity—198 GW
Total RE Capacity (w/o hydro)—312 GW
Total RE Capacity (w/ hydro)—1,320 GW

Global Investment

Total global investment in renewable energy—including financial new investment and small-scale investment —jumped in 2010 to a record $211 billion. China attracted nearly $50 billion, making it the leader for the second year in a row.

RE Jobs

Globally, there are more than 3.5 million direct jobs in renewable energy industries—about half of them in the biofuels industry, with additional indirect jobs well beyond this figure.

"In general, the global renewable energy market remains in a state of flux as policymakers continue to be challenged to set realistic and achievable targets and to link them to appropriate long-term policy mechanisms."

—2011 Global Status Report

Policy at a Glance

More than 115 countries now have renewable energy targets or support policies in place. More than half of those countries are developing countries.

Policy targets now exist in at least 98 countries—most targets are for shares of electricity and typically aim at 10% to 30% of total electricity within the next 1 to 2 decades.

Of all the policies, feed-in tariffs (FITs; also called premium payments, advanced renewable tariffs, and minimum price standards) remain the most common. By early 2011, at least 61 countries and 26 states/provinces had FITs.

Several countries—including the Czech Republic, Italy, Spain, and Australia—are revising PV FITs to dampen the booming rate of installations, which are far exceeding expectations due to the unprecedented price reductions in PV that occurred in 2009 and 2010. The developing countries of Malaysia, Ecuador, and Uganda introduced new FIT policies in 2010 and early 2011.

Another common policy is the "quota" or renewable portfolio standard (RPS). By early 2011, quota/RPS policies existed in 10 countries at the national level and in at least 50 other jurisdictions at the state, provincial, or regional level.

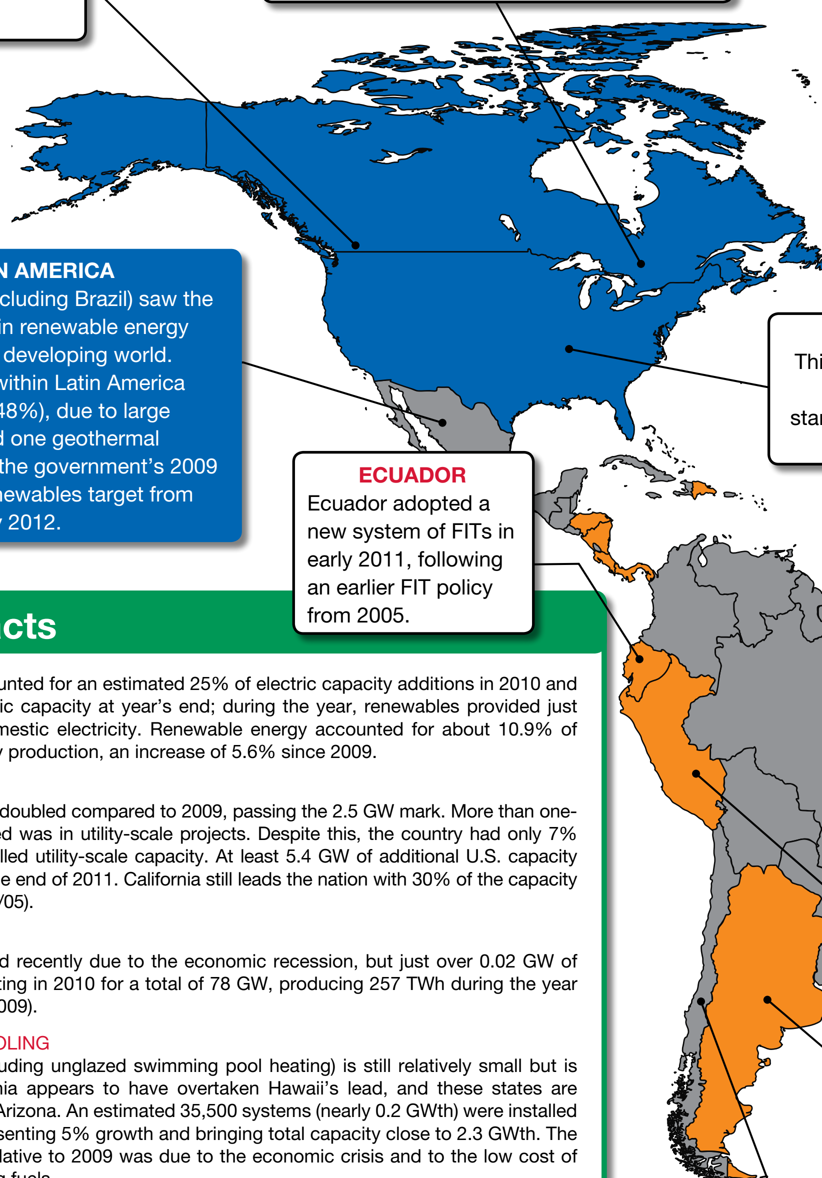
The Americas

CANADA
Canada generates roughly 61% of its electricity from hydropower.

CANADA
As of the end of 2010, the world's largest PV plant was the 0.08 GW Sarnia facility in Ontario, Canada, which is expected to make enough energy for 12,800 homes.

NORTH AMERICA
North America's share of global solar cell manufacturing was 5%, with a disproportionately large share of thin-film products. Almost half of North American production was thin-film.

U.S. Stats
Wind Power Capacity: 40.2 GW
Biomass: 10 GW
PV Capacity: 2.5 GW
Geothermal: 3.1 GW
Solar Thermal (CSP): 0.5 GW
Ocean (tidal): 0 GW
Hydropower: 78 GW
Total RE (w/ hydro): 134.3 GW
Total RE (w/o hydro): 56.3 GW



LATIN AMERICA
Latin America (excluding Brazil) saw the biggest increase in renewable energy investment in the developing world. The largest gain within Latin America was in Mexico (348%), due to large wind projects and one geothermal project following the government's 2009 increase of its renewables target from 3.3% to 7.6 % by 2012.

UNITED STATES
Thirty U.S. states (plus Washington, D.C.) have renewable portfolio standard policies, and six more have nonbinding policy goals.

ECUADOR
Ecuador adopted a new system of FITs in early 2011, following an earlier FIT policy from 2005.

LATIN AMERICA
In Latin America and the Caribbean, total installed wind capacity rose 54% during 2010, with Brazil and Mexico each adding about 0.3 GW. Latin America still accounts for a very small share of global wind capacity.

BRAZIL
Roughly 80% of Brazil's electricity comes from hydropower.

PERU
In 2010, Peru's RE investment doubled to $480 million.

ARGENTINA
Argentina introduced a national tariff for PV systems in certain provinces, making it the first Latin American country to do so. The country's RE investment also increased by 568%, to $740 million.

CHILE
Chile's RE investment increased 21% to $960 million, while the government reduced its 2020 RE electricity target from 10% to 8%.

U.S. Fast Facts

Renewable energy accounted for an estimated 25% of electric capacity additions in 2010 and 11.6% of existing electric capacity at year's end; during the year, renewables provided just over 10.3% of total domestic electricity. Renewable energy accounted for about 10.9% of domestic primary energy production, an increase of 5.6% since 2009.

SOLAR
U.S. PV capacity almost doubled compared to 2009, passing the 2.5 GW mark. More than one-fourth the capacity added was in utility-scale projects. Despite this, the country had only 7% of the world's total installed utility-scale capacity. At least 5.4 GW of additional U.S. capacity was under contract by the end of 2011. California still leads the nation with 30% of the capacity (down from 80% in 2004/05).

HYDRO
Development has slowed recently due to the economic recession, but just over 0.02 GW of new hydro began operating in 2010 for a total of 78 GW, producing 257 TWh during the year (up from 233.6 TWh in 2009).

SOLAR HEATING & COOLING
This U.S. capacity (excluding unglazed swimming pool heating) is still relatively small but is gaining ground. California appears to have overtaken Hawaii's lead, and these states are followed by Florida and Arizona. An estimated 35,500 systems (nearly 0.2 GWth) were installed nationally in 2010, representing 5% growth and bringing total capacity close to 2.3 GWth. The slower rate of growth relative to 2009 was due to the economic crisis and to the low cost of competing home-heating fuels.

WIND
Due to the late extension of the investment tax credit (ITC); low natural gas and electricity prices; and transmission access issues, the United States added just over 5 GW in 2010, compared with more than 10 GW the previous year—bringing total wind power capacity to 40.2 GW, a 15% increase over 2009. By the end of 2011, wind accounted for 2.3% of electricity generation (up from 1.8% in 2009), enough to supply electricity for more than 10 million homes. In 2010, the United States and Canada together accounted for about 15% of the global capacity, including an estimated 0.02 GW of small-scale wind turbine capacity added in the United States.

CONCENTRATING SOLAR THERMAL
The year ended with 509 MW of total concentrating solar thermal power (CSP) capacity after adding 78 MW, including two hybrid plants—a 2 MW add-on to a coal plant and a 75 MW add-on to an integrated-gas combined-cycle power plant (the first in the state of Florida).

BIOFUELS
The United States and Brazil accounted for 88% of global ethanol production. After several years as a net importer, the United States overtook Brazil as the world's leading ethanol exporter.

KEY
- Countries with local feed-in tariffs
- Countries with national feed-in tariffs

EUROPE HIGHLIGHTS

In the CZECH REPUBLIC, the combination of high FIT rates and the reduction in PV equipment costs led to a second strong year (1.5 GW), lifting the country from 65 MW in 2008 to nearly 2 GW of existing capacity by the end of 2010. In March 2011, the country cut all FIT rates for ground-mounted PV installations that were not yet interconnected with the grid.

SCOTLAND is on track to exceed its 2007 target for 31% of total electricity generation from renewables by 2011. The Scottish government raised its 2020 target for RE electricity generation from 50% to 80%.

The **UNITED KINGDOM** decided in 2010 to replace its existing quota policy with a FIT, starting in 2013.

In May 2011, ITALY cut tariffs for PV by 22% to 30% for 2011, by 23% to 45% for 2012, and by 10% to 45% for 2013. A project ceiling of 1 MW on rooftops and 0.2 MW for ground-mounted systems was also imposed to limit the total cost to EUR $6–7 billion by the end of 2016, when roughly 23 GW are expected to be installed.

Although it ranked 18th overall, **CYPRUS** remained the world solar heating leader on a per capita basis at the end of 2009, with 554 kilowatts-thermal (kWth) per 1,000 inhabitants.

Despite financial problems that led to the government temporarily blocking project applications, **GREECE** added almost 0.2 GW of PV in 2010—more than quadrupling its 2009 additions.

On a per capita basis, **AUSTRIA**, which had 315 kWth per 1,000 inhabitants in 2009, remained the solar heating leader in continental Europe, followed by Greece (266 kWth) and Germany (102 kWth).

TURKEY enacted a long-awaited renewable energy law that replaces the existing single-rate FIT with technology-specific FIT rates over a 10-year term for wind, geothermal, biomass, biogas, and solar, with bonus payments if hardware components are made in Turkey.

BULGARIA, through its new Renewable Energy Act of June 2011, put an annual cap on new projects receiving the FIT prices by applying a quota.

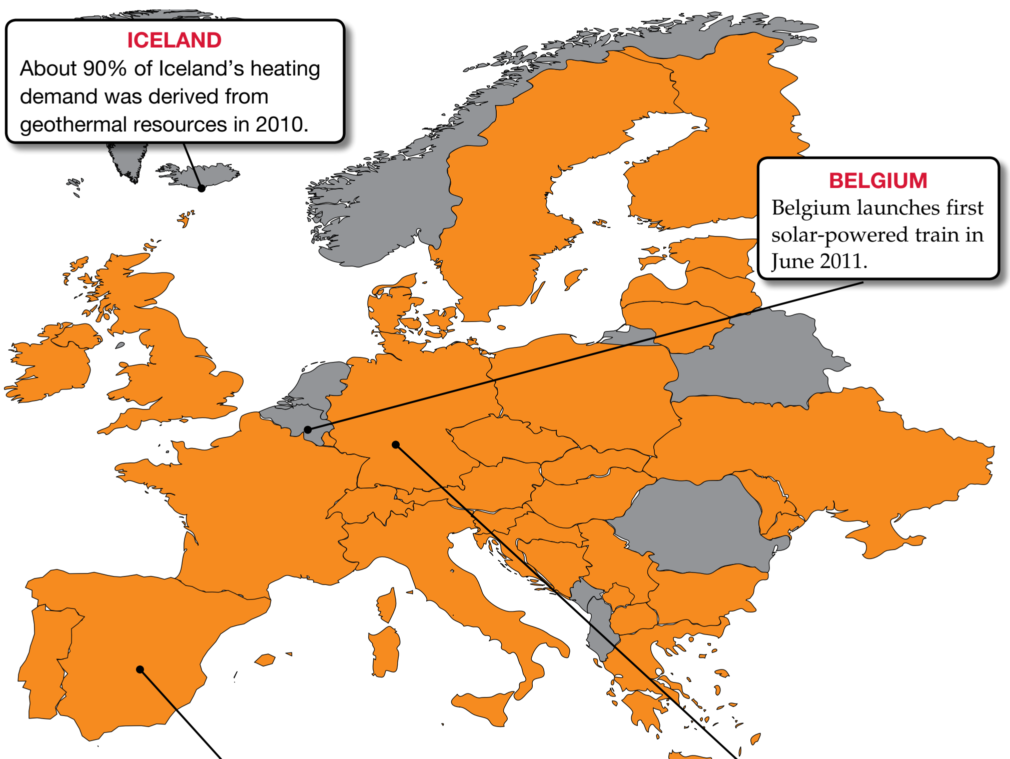
BOSNIA is planning its first wind farm, and in 2010, **ROMANIA** began constructing what will be Europe's largest onshore wind farm.

The European Union

In the European Union, renewables accounted for an estimated 41% of newly installed electrical capacity in 2010, with PV accounting for more than half of the total. Although the share was significantly lower than the more than 60% of total capacity added in 2009, more renewable power capacity was added in Europe than ever before (22.6 GW), with total installations up 31% over the previous year (17.5 GW).

SOLAR The EU dominated global PV capacity, accounting for 80% of the world total with about 13.2 GW newly installed—enough to meet the electricity consumption of some 10 million European households. For the first time ever, Europe added more PV than wind capacity during 2010, led by Germany and Italy.

WIND Germany maintained the lead in Europe, with 27.2 GW operating in 2010, but Spain led with new installations (nearly 1.8 GW). Emerging markets include Bulgaria, Lithuania, Poland, and Romania; in addition, Cyprus installed its first wind turbines (0.08 GW).



SPAIN

In Spain, the $0.55 per kWh FIT level for PV, as set in 2007, still remains. As a result of a cap on ground-mounted systems and uncertainties associated with the new regulatory framework, PV installations were well below the 2008 peak and its goal for 8.3 GW of PV capacity for 2020 was adjusted to 6.7 GW.

Despite having its slowest growth since 2003, Spain again led Europe in new wind installations, adding nearly 1.8 GW for a total of more than 20.7 GW—ranking it No. 3 for new wind capacity.

Despite having less capacity in operation than Germany did, Spain produced more electricity with wind (43 TWh) in 2010, due largely to high winds in Spain and more advanced turbines.

GERMANY

In 2010, Germany met 11% of its total final energy consumption with RE sources. Wind power accounted for nearly 36% of RE generation, followed by biomass, hydropower, and PV.

The country added more PV (7.4 GW) in 2010 than the entire world did the previous year, ending 2010 with 17.3 GW of existing capacity.

During the first quarter of 2011, Germany generated 2.75 TWh of electricity with PV, an increase of 87% over the same period in 2010. Its 2010 target of 3.5 GWp for newly installed PV capacity was easily exceeded. This led to an agreement with the PV industry for an annual reduction in FITs if a cap of 3.5 GW is surpassed. The country also introduced a goal to achieve 35% renewable electricity by 2020.

Africa & the Middle East

At least 20 countries in the Middle East, North Africa, and sub-Saharan Africa are increasing RE capacity. Africa achieved the largest percent increase in RE investment among developing country regions apart from China, India, and Brazil. Total investment rose from $750 million to $3.6 billion, largely as a result of strong performances in Egypt and Kenya.

SOLAR More than 500,000 PV systems were in use in 2007, with more than half of these in South Africa and Kenya. In North Africa and the Middle East, at least 1.2 GW of concentrating solar thermal power capacity is in the pipeline, including plants under construction in the United Arab Emirates and planned in Algeria, Egypt, Jordan, Tunisia, and Morocco.

WIND Africa still accounts for a very small share of global wind power capacity, but projects are planned or under way in Egypt, Ethiopia, Kenya, Morocco, Nigeria, Tunisia, and Tanzania—including Kenya's 0.3 GW Lake Turkana project and 0.7 GW of capacity under construction in Morocco.

FOR ANOTHER PERSPECTIVE, see how RE measures up against fossil fuels. Check out BP's *Statistical Review of World Energy* at www.bp.com

KUWAIT
Kuwait will aim for 5% RE capacity by 2020.

IRAN
IRAN did not add wind capacity during 2010, but it remains the only country in the Middle East with large-scale wind projects (0.9 GW total).

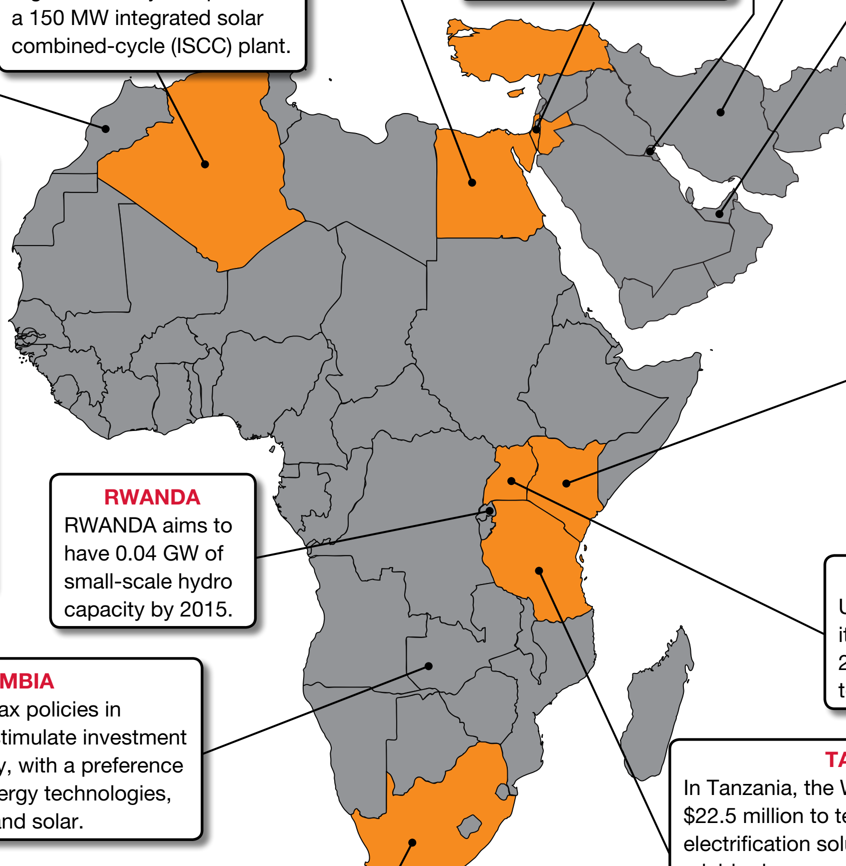
EGYPT
Egypt added 0.1 GW for a total of 550 MW in wind capacity—the most of any African country. It also had an estimated 1 GWth of solar thermal systems by the end of 2010.

ISRAEL
Israel reduced its 2020 RE electricity target from 10% to 7%. The country ranked second in world solar heating per capita with 391 kWth.

MOROCCO
Morocco inaugurated the 140 MW Dahr Saadane wind project in 2010.

ALGERIA
Algeria recently completed a 150 MW integrated solar combined-cycle (ISCC) plant.

UNITED ARAB EMIRATES
The United Arab Emirates aims to have 5% of its energy derived from RE by 2030.



AFRICA
Several African rural electrification programs launched since the early 2000s have involved solar home system (SHS) projects, especially in western Africa (Mali, Senegal, and Mauritania). Whether through fee-for-service or household-based programs (microfinance or cash), the SHS market in Africa continues to expand.

KENYA
As of 2005, Kenya was home to just over 150,000 PV systems, with a median size of 25 W peak, and coverage had reached a reported 300,000 households.

RWANDA
RWANDA aims to have 0.04 GW of small-scale hydro capacity by 2015.

UGANDA
Uganda implemented its existing FIT in early 2011 for 11 separate technologies.

ZAMBIA
Zambia relaxed tax policies in mining areas to stimulate investment in power capacity, with a preference for renewable energy technologies, including hydro and solar.

TANZANIA
In Tanzania, the World Bank invested $22.5 million to test new off-grid electrification solutions—particularly mini-hydropower generation, biomass cogeneration, and solar energy—that are expected to be scaled up in the future.

SOLAR HOT WATER
Solar hot water installations are increasing in Egypt, Ethiopia, Kenya, Morocco, Namibia, South Africa, Tunisia, and Zimbabwe. Egypt had an estimated 1 GWth of solar thermal systems by the end of 2010, and Morocco's collectors totaled an estimated 0.2 GWth.

SOUTH AFRICA
South Africa introduced a target for 1 million new SHW installations by 2014.

KEY
- Countries with local feed-in tariffs
- Countries with national feed-in tariffs

Asia & Australia

CHINA

As a result of favorable government policies, CHINA led the world in the installation of wind turbines and solar thermal systems, and was the top hydropower producer in 2010. The country added an estimated 29 GW of grid-connected renewable capacity, for a total of 263 GW, an increase of 12% compared with 2009. RE accounted for about 26% of China's total installed electric capacity in 2010, 18% of generation, and more than 9% of final energy consumption. China's previous target for a 10% share of total primary energy from RE by 2010 was almost met, as the share exceeded 9%, but attention has shifted to the new target for 2020—a 15% share of non-fossil (renewables and nuclear) final energy by 2020.

The first major offshore wind farm outside of Europe, China's 0.1 GW Donghai Bridge near Shanghai, began operation in July 2010; three months later, China began construction of four projects off the coast of Jiangsu, totaling 1 GW and due to be completed by 2014.

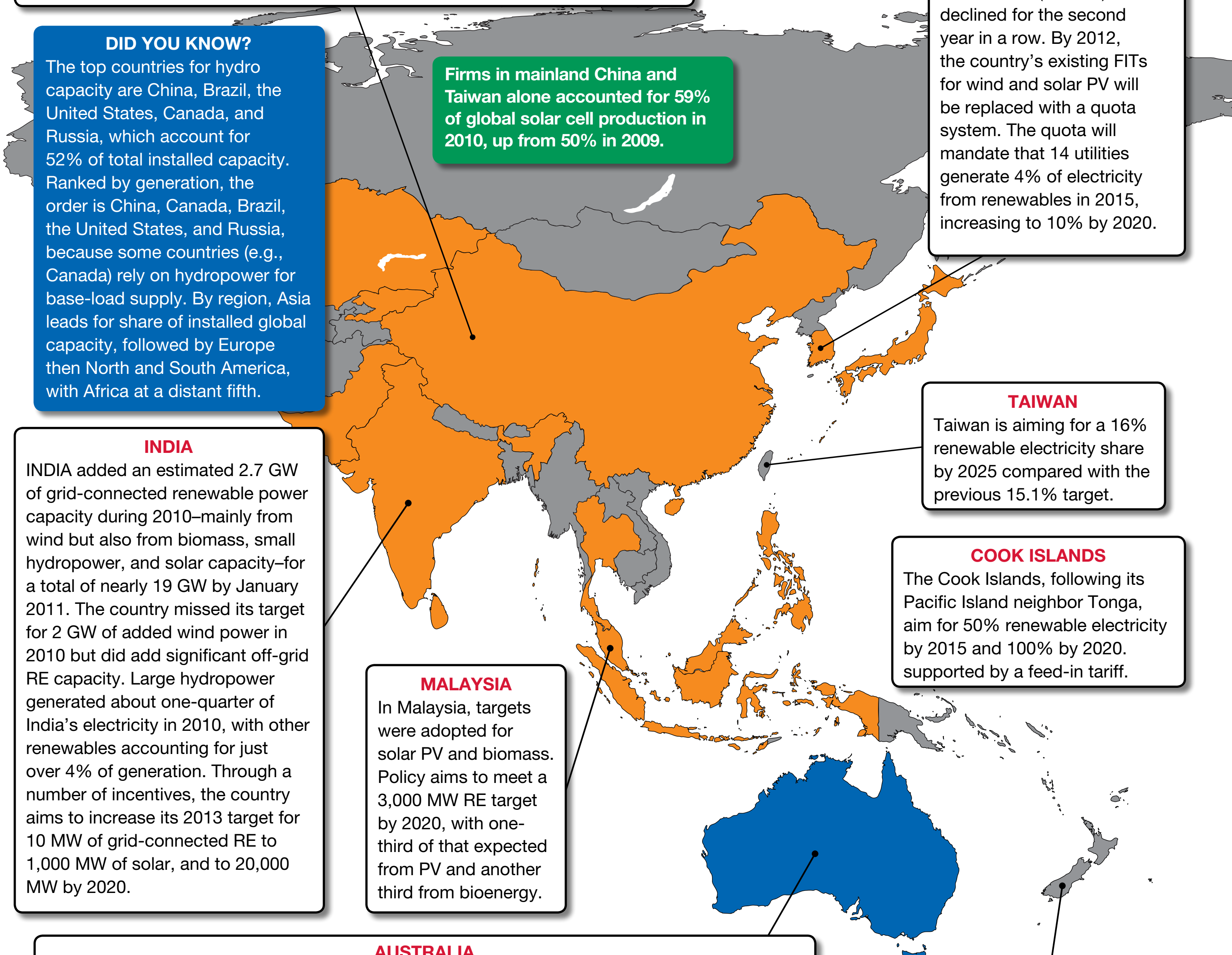
SOUTH KOREA

South Korea's PV installations (0.1 GW) declined for the second year in a row. By 2012, the country's existing FITs for wind and solar PV will be replaced with a quota system. The quota will mandate that 14 utilities generate 4% of electricity from renewables in 2015, increasing to 10% by 2020.

DID YOU KNOW?

The top countries for hydro capacity are China, Brazil, the United States, Canada, and Russia, which account for 52% of total installed capacity. Ranked by generation, the order is China, Canada, Brazil, the United States, and Russia, because some countries (e.g., Canada) rely on hydropower for base-load supply. By region, Asia leads for share of installed global capacity, followed by Europe then North and South America, with Africa at a distant fifth.

Firms in mainland China and Taiwan alone accounted for 59% of global solar cell production in 2010, up from 50% in 2009.



TAIWAN

Taiwan is aiming for a 16% renewable electricity share by 2025 compared with the previous 15.1% target.

INDIA

INDIA added an estimated 2.7 GW of grid-connected renewable power capacity during 2010–mainly from wind but also from biomass, small hydropower, and solar capacity–for a total of nearly 19 GW by January 2011. The country missed its target for 2 GW of added wind power in 2010 but did add significant off-grid RE capacity. Large hydropower generated about one-quarter of India's electricity in 2010, with other renewables accounting for just over 4% of generation. Through a number of incentives, the country aims to increase its 2013 target for 10 MW of grid-connected RE to 1,000 MW of solar, and to 20,000 MW by 2020.

COOK ISLANDS

The Cook Islands, following its Pacific Island neighbor Tonga, aim for 50% renewable electricity by 2015 and 100% by 2020. supported by a feed-in tariff.

MALAYSIA

In Malaysia, targets were adopted for solar PV and biomass. Policy aims to meet a 3,000 MW RE target by 2020, with one-third of that expected from PV and another third from bioenergy.

AUSTRALIA

Australia met its original 2010 target of 9.5 TWh for renewable electricity well before 2010 and consequently revised the target to 45 TWh target by 2020. This target will be met in part through uncapped fixed-price certificates bought and sold in a national certificate market.

In 2010, Australia's PV capacity (0.3 GW) grew fourfold relative to 2009. But, in December 2010, the federal government adjusted the rooftop PV credit to slow it down faster than was originally planned due to the impact on electricity prices, continuing strong industry growth, and the resulting lower demand for other RE technologies such as solar water heaters. Then, in May 2011, the country cut AUD 220 million from its 1.5 billion Solar Flagship program, which aims for four grid-connected power stations.

NEW ZEALAND

New Zealand, along with Norway and Iceland, lead the world in per capita generation of hydropower.

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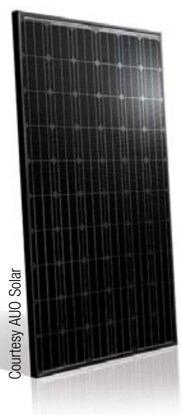
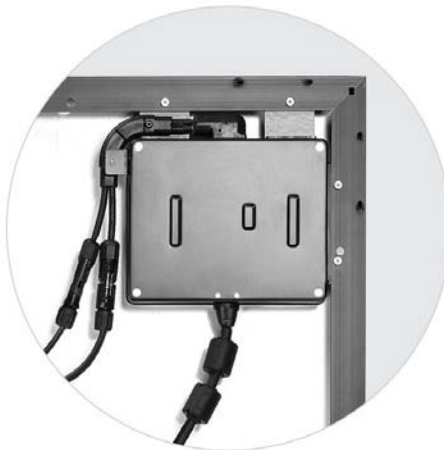

Courtesy AUO Solar

AUO Solar (www.auosolar.com) and SolarBridge Technologies (www.solarbridgetech.com) have teamed up to create the AUO AC Unison, which features a SolarBridge Pantheon microinverter pre-installed on a AUO Solar 250 W monocrystalline module. The frame-attached inverter/module combination will be listed as a complete assembly to meet UL 1741 requirements for AC modules. Similar to other distributed MPPT solutions, this AC module will offer module-level monitoring via the AUO Solar Web Portal. The AUO AC Unison PM250MA0 is expected to begin shipping in the third quarter of this year and will be sold by AUO Solar through its network of distribution partners.

—Justine Sanchez

Courtesy Outback Power

OutBack Power

Radian Series Inverter/Charger

OutBack Power (www.outbackpower.com) is releasing its Radian Series GS8048 inverter, an 8 kW inverter/charger that has been redesigned to address three constraints of the company's current OutBack FX and GTFX lines. The Radian series is designed for both grid-interactive and stand-alone applications; has a split-phase 120/240 VAC output; and provides dual AC inputs so both the grid *and* a generator may be utilized. The GS8048 has a 48 VDC nominal input voltage, 30 W idle consumption, and surge specifications of 16.97 kVA (100 ms), 12 kVA (5 seconds), and 9 kVA (30 minute). Multiple units can be combined for systems from 8 to 80 kW.

—Justine Sanchez

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Solar in a Suitcase

In Nigeria, maternal mortality rates are among the highest in the world, second only to India. For every 100,000 births, an estimated 1,100 mothers die. With the rationed and often unreliable electricity supply throughout the country, night deliveries are frequently carried out in near darkness, and clinics are forced to perform emergency cesarean sections by flashlight—or worse yet, postpone the critical procedures until daylight or electricity can be restored.

We Care Solar (WCS) cofounders Laura Stachel, M.D., and Hal Aronson, Ph.D., hope to change that. The husband and wife team came up with the concept for a suitcase-sized solar-electric system that can be used to power LED medical task lighting, charge cell phones and batteries, and provide electricity to 12 VDC devices.

Inspired by the deplorable conditions she witnessed on a research trip to Nigeria in 2008, Stachel, a licensed obstetrician and gynecologist in California who left her practice to work in public health, enlisted her husband's help to develop a renewable power solution that could be easily transported through customs.

Aronson, a solar energy designer and educator in California, went to work in his shop, tinkering with spare components and different configurations. His efforts resulted in a prototype turnkey PV system that fits in a watertight, protective hard case.

When Stachel returned to Nigeria the following year with the solar suitcase, it was clear that Aronson had hit the mark with his design. "I hadn't intended to leave the kit there. It was an experiment at that stage. I had only intended to use it for demonstration purposes, but the people at the hospital where I worked begged me to leave it—they said it would be the difference between life and death for some, and I couldn't argue with that," says Stachel.

Since then, more than 120 solar suitcases have been deployed to 15 countries. Funding to make and ship the solar suitcases, which cost about $1,500 to produce, is largely from individual donations, grants, or contributions from third-party groups.

In most cases, it is a one-on-one effort, Stachel says, where individual donations provide the funding for one case to be deployed to a particular clinic. But the group also organizes solar suitcase programs, where multiple kits are distributed throughout a region—typically as a result of grant funding secured by a nongovernmental or nonprofit organization. In this case, WCS sends volunteers to deploy the suitcases and train the users.

The latest design uses two to four 20-watt monocrystalline PV modules that were specially developed for the solar suitcase

Courtesy WCS (2)

Get Hands On...

Learn to build a solar suitcase through Solar Energy International. Though designed for the professional development of K–12 teachers, SEI's workshop is open to anyone interested in learning and lending a helping hand. The solar suitcases built in the class are distributed throughout the world. **www.solarenergy.org**

by Everbright Solar in Fremont, California. The modules are mounted on rigid substrate, weigh about half as much as a conventional framed module, and are sized to fit into the case.

The typical system includes a Morningstar ProStar 15-amp charge controller, a 15 amp-hour sealed lead-acid battery, and 6 watts of high-efficiency LED task lights—all contained in the case. The standard obstetric kit also comes with a universal cell phone charger, a AA/AAA battery charger, outlets for 12 VDC devices, a fetal heart-rate monitor, LED headlamps, and rechargeable AA and AAA batteries. WCS worked with Holly Solar Products in Petaluma, California, to develop high-efficiency lamps that are rugged enough to last up to 20 years and bright enough to conduct surgery.

Though designed to be portable, the solar suitcase can also be used as a stationary system—the suitcase itself bolts to the wall and the modules can be mounted on a rooftop. An expansion kit is also available for using larger batteries and adding more LEDs.

"It is an out-of-the-box, plug-and-play experience. Someone who has never done anything with solar electricity can get the system running in less than a minute. If they choose to use it for a permanent installation, then it can be fully operational within two hours of opening the kit. It is that easy to use," Aronson says.

Though originally designed to support obstetric care, the solar suitcase has been used in a range of medical and humanitarian settings. Seven suitcases were deployed to Haiti after the 2010 earthquake.

The latest batch of solar suitcases sent to Nigeria contained remote monitors, so data can be collected about the function of the solar suitcases in clinical situations and ultimately be used to improve the design for future applications. Looking ahead, WCS has partnered with other groups in hopes of securing funding for nearly 150 solar suitcase requests in Uganda, Nepal, Malawi, and Haiti. Stachel and Aronson remain determined to meet demand and do what they can improve maternal healthcare around the world. Their motivation comes from the feedback they receive.

"Health workers tells us they are no longer afraid to work at night, that they can do medical procedures with ease, that they can do the job they were trained to do," Stachel says. "Surgeons tell us the light allows them to see the tissue layers better, and they can perform surgeries more efficiently and safely."

—Kelly Davidson

Get Involved...

Support the solar suitcase movement at **www.wecaresolar.org.**

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Graph showing battery voltage, input voltage and kWh

Graph showing same information as the above graph but in bar mode

Graph showing minimized mode

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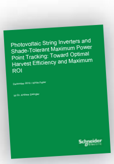

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PV Challenges
in the Nation's Capitol

Courtesy Andy Kerr (3)

Urban solar installations often come with their siting challenges, as did this Capitol Hill townhouse in Washington, DC. First, its historic district designation meant that the array could not be visible from across the street. Second, the townhouse's age (86 years) meant that a lot more weight on the roof could cause more problems. With only 742 square feet of roof space—plus a chimney and plumbing vent penetrating the roof—the solar access was extremely limited, and some of that space would be needed for a future SHW system. A neighbor's tree also caused morning shading on the eastern roof. Finally, a rubber membrane roof meant no roof penetrations.

Ironically, the best solution for each issue yielded poor solutions for the other issues. Creative compromise was needed to find an optimal solution.

To hide the array from view, it would need to be low profile. That was good, since an array with a steeper tilt would mean more wind loading, necessitating heavier ballast to keep the array firmly in place without roof penetrations. A low tilt would be subject to less wind loading, and require less ballast, thus minimizing additional weight on the roof.

A couple of 90° elbows and two short pieces of plastic vent pipe were used to reroute the vent. If the design choice had been parallel-to-roof modules, placed end-to-end and side-to-side, the only option would have been to leave out a module to accommodate the vent.

The goal was to offset as much of my electricity use as possible. While the greatest number of modules could be fit on the roof in a parallel-to-roof array, its energy production would have be 86% of the maximum attainable with an array at an "optimal" tilt (33°). A compromise—tilting the modules at 10°, with three rows of modules carefully placed to avoid shading each other—would yield about 94% of "optimal" production.

Enphase microinverters, which pair one inverter per module, were used to reduce array performance losses due to shading from the chimney and neighboring tree. Shading from the chimney will be resolved by its removal after a direct-vented, high-efficiency gas furnace is installed. Because of chimney shade, two modules are producing less than their neighbors. By using microinverters, only the individual module's performance—not an entire string's output—is affected.

Enphase's Web-based Envoy monitoring system shows early-morning shading (black modules) from the chimney. When the chimney is removed, the shaded modules' production will return to normal.

Overview

Project name: Serrulata

System type: Batteryless grid-tied PV

Installer: Astrum Solar

Date Commissioned: May 1, 2009

Location: Washington, DC

Latitude: 38.89°N

Resource: Solar, 4.7 peak sun-hours

System capacity: 3.0 kW STC

Average annual production: 3,609 kWh

Average annual utility bill offset: 71%

Equipment Specs

Number of modules: 17

PV manufacturer & model: Suntech STP175S-24

Module rating: 175 W STC

Inverters: 17 Enphase Energy M190 microinverters

Inverter rated output: 190 W per inverter

Array installation: Roof

Roofing material: Rubber membrane

Array azimuth: 180°

Tilt: 10°

At the time, the District of Columbia was offering a very enticing rebate of $3 per installed watt. Solar renewable energy credits were also of at the high end of their fluctuating market price, equipment prices had dropped, and installation rates were competitive. Combining these factors with the 30% federal income tax credit, the combination of government and market incentives would result in a simple payback on this PV system of 1.3 years.

Further adding to the overall efficiency is a new furnace that uses less electricity and its new blower, which will make the air-conditioning more efficient. Adding better-insulated, new windows (which will also open easier to facilitate natural cooling) will also reduce electrical loads, allowing the home to get closer to—and maybe achieve—net-zero electrical energy.

—Andy Kerr

More steeply tilted modules would have required more concrete block ballast, putting an unwanted load on the roof.

Determining PV Array Maximum System Voltage

PV modules, inverters, disconnects, wiring, and overcurrent protection devices are rated to handle only so much voltage. Equipment used for residential and commercial PV systems in the United States is rated up to 600 VDC, so it is important to make sure a PV array is configured so that this 600-volt rating is not exceeded.

In cold, sunny conditions, array voltage will increase—you'll need to account for this when designing your system so the voltage stays below the limit. That involves some math, and knowing the lowest expected ambient temperature at your site.

NEC Article 690.7 dictates that if the PV module manufacturer provides a temperature coefficient of open-circuit voltage (TkVoc), it must be used in the calculation. This coefficient tells us how much a module's voltage will increase per °C below the standard test condition (STC) of 25°C. The temperature coefficient will be listed in volts per °C; millivolts (mV) per °C; or as a percentage per °C. Most module manufacturers provide this data in their module specification sheets.

If a module has a TkVoc of -0.120 V per °C this means that, for each °C *below* 25°C, the module voltage will *increase* by 0.120 volts. If you have a module with a TkVoc given in % per °C, multiply this TkVoc by the module's open-circuit voltage (Voc). A module with a Voc of 36.9 volts and a TkVoc of -0.36% per °C will have a 1.333 voltage increase for each degree below 25°C.

0.0036 × 36.9 V = 0.133 V

Once we have this calculation, we must determine the lowest expected ambient temperature. The *2011 NEC* points us to "Extreme Annual Mean Minimum Design Dry Bulb Temperature" found in the *ASHRAE Handbook—Fundamentals.* If you don't have access to that handbook, this "extreme min" temperature data is now listed for many locations at www.solarabcs.org/permitting/map/.

Let's assume our array uses modules with a Voc = 36.9 volts and a TkVoc = -0.36% per °C, and is located in Albany, New York. The extreme minimum temperature for this location is listed as -23°C. This is 48°C lower than the STC temperature.

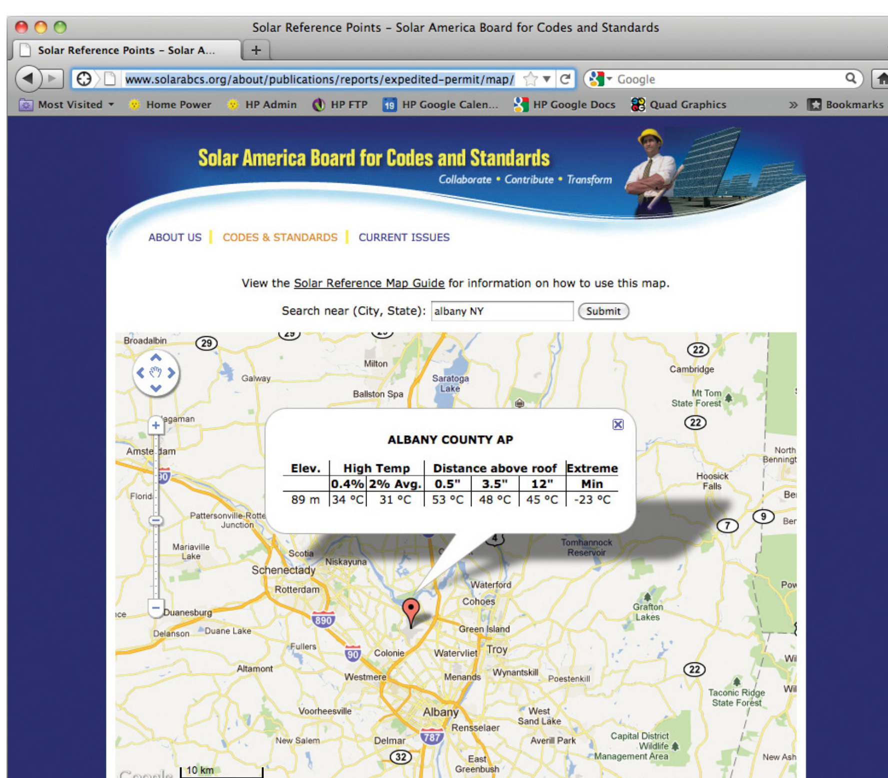
-23°C - 25°C = -48°C

Using this value, along with the TkVoc, results in a module voltage increase of 6.38 volts (48°C × 0.133 V = 6.38 V). That means our maximum module Voc is now 43.28 V.

36.9 V + 6.38 V = 43.28 V

Now that the module voltage has been "adjusted," multiple it by the number of modules in series to determine the maximum system voltage. If our array consists of 12 of these modules in series, the resulting maximum system voltage is 519.4 volts, which is under the 600-volt limit. However, if we had 14 of these modules in series, the 600-volt limit could be exceeded (43.28 V × 14 = 605.9 V) given this location and these modules.

—Justine Sanchez



EV Upgrade

My converted electric GMC Sonoma pickup was featured in the article "Born To Be Wired" in *HP122*. I recently changed my lead-acid (L-A) batteries for a lithium-ion (Li-ion) battery pack, and think your readers will be interested in the results.

In 2007, at the time of the original conversion, knowing the advantages of Li-ion, I checked on the price of these batteries. The cost would have been about $75,000, considerably beyond my budget. Instead, I used 24 6-volt 240 Ah flooded L-A golf-cart batteries (Trojan T-145), which cost about $3,300 (a good price at the time). I expected the batteries to last five years.

I only got about half the expected life from the batteries, mostly because I was out of town often, and unable to properly monitor or maintain the batteries. Several times, I let the electrolyte fall below the top of the plates, and I was initially unaware that the charger I selected was overcharging the batteries (which accelerated electrolyte evaporation). As the battery capacity diminished and the vehicle became less usable, I ended up leaving my beloved project unused in the carport until this past spring.

Rising gas prices and more instability in the Middle East prompted a renewed interest in my EV. Realizing that my unpredictable schedule was still incompatible with regular battery maintenance, I decided to investigate Li-ion batteries again. I was pleased to find that the price had fallen significantly, to about $1.25/Ah/cell (Li-ion cell voltage is about 3.3 V). I choose Manzanita Micro as my source of batteries, and purchased 48 200 Ah Winston lithium iron phosphate ($LiFePO_4$) cells arranged in 12, 12-volt batteries (about 144 V total) for $12,000. Fortunately, Washington state exempts EV conversion components from sales tax, which eased the price.

One aspect of Li-ion batteries is that they need a battery management system (BMS) to ensure that each cell is equally charged. Otherwise, some cells can become overcharged, while others remain undercharged, which leads to premature battery failure. So I also purchased Manzanita Micro's BMS for an additional $3,200.

Courtesy Randy Richmond

The result of changing to Li-ion has been dramatic. Here is a comparison of the before and after values:

EV Batteries: L-A vs. Li-ion

Factor	Lead-Acid	Li-ion (W/BMS)
Cost	$5,000	$15,000
Maximum depth of discharge (%)	50%	100%
Size of battery pack (kWh)	37	28
Usable stored energy (kWh)	18	28
Battery area required (ft.^{2})	12.3	9.5
Battery weight (lb.)	1,730	960
Vehicle weight (lb.)	5,000	4,200
Driving range (miles)	30 – 40*	75
Acceleration, 0 to 60 mph (seconds)	35	21
Wh per mile (approx.)	750	400

* Driving range affected in cold weather.

In addition to these measurable improvements, there have been several more subjective improvements. Compared to L-A batteries, my new batteries provide more stable power through nearly the entire discharge curve, they can be discharged much more deeply without any significant reduction in longevity, their capacity is affected very little by cold temperatures, and their capacity isn't affected by sitting idle for several days. I have found switching to Li-ion batteries well worth the extra initial cost. With Li-ion's 3,000- to 5,000-cycle life, the total cost of ownership should easily be less than I had with L-A.

Randy Richmond • Woodinville, Washington

Grid Parity

Thanks for the article on grid parity in *HP145*, and the spreadsheet for calculating the present value of the two options. However, I think the example is overly conservative, at least for my location and situation.

I am a PV systems installer in northern California. My average installation cost is about $4.50 per watt (or less). This is considerably lower than the $5 per watt estimated in the spreadsheet. I use inverters that are guaranteed for 25 years, so there is not a midlife replacement cost. I have had numerous discussions with Sandia concerning system degradation over time and they claim to measure about 0.5% to 1% over the first two or three years, and very little or no loss after that. Therefore, an estimated degradation of 1% a year is much larger than historical measurements indicate (it is the normal guarantee, but not the normal performance). The estimated tree trimming or maintenance costs seem excessive for most installations (but these costs are minor and don't impact the outcome very much). In my utility district, the average electrical cost is currently about $0.25 per kWh (depending upon many variables such as time of use, tiered use, baselines, etc.). Also, my utility (PG&E) has been increasing electrical power costs by almost 7% a year for the past 30 years and shows no signs of slowing that rate. My guess is that it will increase even faster than 7% over the next 25 years.

Using values that apply to my location, I calculate that the present value of the solar electricity is $45,000 whereas the utility power is $126,000—almost three times as much. In addition, the spreadsheet assumes that the value of the solar equipment immediately goes to zero, which is obviously not the case; in fact it increases the overall value of home by more than the installation cost.

Adding the value of the federal tax credit brings the present value of the solar-electric system down to about $30,000—versus $126,000! I think the question is a no-brainer—solar electricity is much less expensive than grid electricity. Grid parity was reached long ago.

Charles Hoes • Zamora, California

Wow! I can see why California is so far ahead of the rest of the country with regards to solar energy system demand. It must be great to be an installer there!

I chose the New Jersey example simply because it is what I'm most familiar with—it's where I live. But the main point of the article is that there are many variables, and anyone can just plug theirs into the calculator and calculate it:

- *If you're paying for a high-quality 25-year-warranteed inverter, you can zero out that item in the maintenance section.*
- *If you have no trees anywhere near your house, you can zero that out.*
- *If efficiency losses are only 0.25% per year on average, adjust that variable accordingly.*

The question of how fast the price of grid electricity will rise versus normal inflation is an interesting one. In the example, I assumed it would, on average, outpace inflation by 2% per year. While this has been true nationally since 2004, prior to that it was slower, and sometimes it was even less than inflation (such as from 1983 to 1998). Again, your own guess for your own local situation can be plugged into Variables 12 and 13.

As to the federal subsidy, I intentionally left that out, since the article is about comparing the cost of solar to the cost of grid electricity without *any government subsidies. But if you want to account for the federal subsidy, it is*

easy to do: Just multiply the installed cost per watt by 0.70.

Note that the calculator does not *assume that the value of the modules goes to zero immediately. You can assume that their value will be zero at the end of 25 years (or whatever life cycle you've chosen). You would then need to account for the cost of removing them and disposing of them, entering this as a negative number. In the example I used, I was able to sell them for just enough to cover the cost of removal and disposal, so the net cost was zero. If you want to assume that you'll be able to sell them for more, just put in the total net amount that you think you'll be able to get for them (in today's dollars and as a positive number), in Variable 14.*

Glad to hear that you are living in "solar heaven" out there. I'm confident that the rest of the country is heading in that direction!

Jay Tyson

Purchase U.S. Batteries

In recent months, the issue of battery manufacturing safety in China has made the news headlines. However, it hasn't made as much news in the RE world as I would like to see. After I read Kelly Davidson's excellent article last month about recycling, I'm prompted to elaborate on battery manufacturing, and why it's a good idea to buy batteries made in the United States.

The Chinese Ministry of the Environment has forced the closure of hundreds of the country's battery manufacturing plants due to their poor handling of lead used in making lead acid batteries. Lead is very toxic and expensive to handle safely, both for workers and the environment. For example, according to Reuters, China phased out 583 lead-acid producers, processors, and recyclers as of mid-July 2011. The recent crackdown covered 1,930 plants, 1,015 of which were temporally closed for upgrading. That is a staggering number of plants to shut down, even for a little while.

While I'm not against the manufacture of batteries or anything else made in China, I'm concerned about these revelations. It's a good thing that the Chinese government is improving its environmental standards, but will these standards be as high as our domestic standards, and how long will they be in place? What is its commitment?

Renewable energy is not sustainable as long as we prioritize short-term costs over long-term environmental goals and workplace safety. This includes the manufacture of batteries, PV modules, inverters, and balance-of-system components. As equipment gets less expensive, I think it is time to consider more seriously where our equipment comes from and how it's made, not just its cost at time of purchase.

There is also the transportation of batteries to consider when choosing whether to buy American or not. I wonder about the embedded energy in a battery that is made in China, shipped across the ocean, used in the United States, and then shipped back to China for recycling. That's a lot of lead getting shipped around the planet. Again, wouldn't it make more sense to manufacture and recycle lead-acid batteries here, safely and efficiently?

Jay Peltz • Redway, California

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Tweaking an SHW System

I recently had a solar hot water (SHW) system installed on my house. It is a closed-loop, evacuated-tube system with a heat exchanger in the storage tank. The differential control (a Caleffi Solar Plus) provides variable pump speed control. Currently, it is using factory defaults for the conditions that determine pump speed. The system has four temperature sensors and a data logger, which help me keep tabs on its function.

I like the idea of a variable-speed pump because it seems like it can add efficiency to an SHW system—just like an MPPT controller does to solar-electric systems. That said, I am not sure what conditions drive the efficiency of the SHW system. Should the control be set for lower flows and higher temperatures, or higher flows and lower temperatures? I know there is more heat transfer at the exchanger with a higher temperature difference between the transfer fluid and tank water, but I am not sure how that balances with the collectors' lower efficiencies at higher temperatures.

Is there a reference I can use to figure this out? I am not looking for specific numbers—more like basic explanations of relationships between the parts of the system and what to look for as a sign of how well an SHW system is performing. Perhaps it's something like checking transfer-fluid temperature drop across the heat exchanger versus the temperature rise at the collector.

Jack Herndon • Seattle, Washington

An ideal collector loop of any SHW system would operate at a difference in temperature of just a few degrees between the inlet and outlet temperatures of the collectors. The higher this differential, the more heat is lost to the outside atmosphere.

This loss is dependent on the outside temperature. Although evacuated tubes are more resistant to heat loss, they are not immune to it. If you're seeing a temperature difference of 50°F or greater, your system is suffering from a low flow rate problem. A system with a 20°F difference is much closer to operating at an "ideal" temperature.

The ideal is a compromise between the lower inlet/outlet differential to minimize heat loss, and a high-enough differential to prevent the control from short-cycling. Short-cycling will occur with too high of a flow rate and will be noticeable—the system will turning on and off excessively. Turning on and off is normal in the early morning and late afternoon and in cloudy weather, but shouldn't happen in mid-day bright sun.

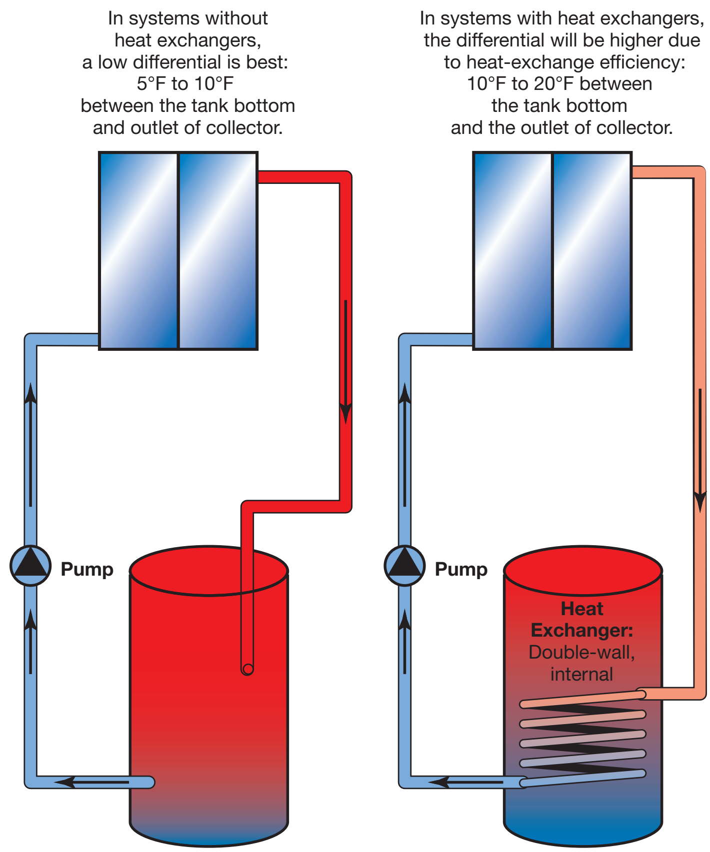
Chuck Marken • *Home Power* solar thermal editor

Thermostat Dilemma

Is it more energy efficient to turn off your home's heat when you're going to be gone all day, or to leave it at a slightly lowered set point? I realize that this is likely a complex calculation involving volume of space, outside temperatures, building envelope and insulation, number of degrees in drop and recovery, elapsed time, type and cost of heating fuel, etc. But perhaps there are some general rules or simplified formulas that can direct a homeowner on the best approach.

Scott Depew • via e-mail

Temperature Differentials, With & Without Heat Exchangers



The short answer is that leaving your thermostat at a very low set point will almost always result in lower energy consumption. The long answer follows.

For most residential heating systems, the thermostat controls the heating system to maintain the set point (the temperature you set). It does this by turning the heating system on and off. As you would expect, the room temperature will fluctuate from the set point, unless you allow the heating system to cycle on and off very quickly, which will prematurely age your equipment.

During cold weather, your house is continually losing heat to the outdoors. It does this in several ways. Heat is lost by conduction through the surfaces of the house; warm air exits the house while cold air enters (infiltration); and to a lesser extent, your house radiates heat outward. Of course, it gets more complicated, since your house has a great many parts, each of which have different thermal conductivities, thermal capacities, and radiative properties.

The net effect of all this complicated heat transfer is that a typical house will (almost always) lose more heat when the inside temperature becomes higher relative to outside. I say "almost always" because it's possible to have net heat gain on a cold day if it's very sunny, and your house is well-insulated and sealed.

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Programmable thermostats make it easy for homeowners to save energy and still come home (or wake up) to a comfortable house.

Another effect that we should discuss is how your furnace or boiler delivers heat to your house. Most furnaces and boilers run either at full fire or off. When the combustion cycle starts, a certain amount of heat is used to warm up the heat exchanger and the duct or pipes. When the furnace or boiler shuts off, much of this heat will be lost. (Having your ducts taped and insulated will help minimize this.) Any energy-saving strategy should also try to minimize the cycling of your heating system.

The most energy-saving alternative is to let your house become as cold as possible while you're not home. What's "as cold as possible"?

Don't allow anything fragile (water pipes, for example) to freeze.

Allow just enough time for your heating system to bring the house temperature to its set point the moment you walk in the door.

But wait, there's another complication. Even though the air temperature in your house may be at the perfect set point, you may feel less comfortable under these conditions. That's because the surfaces in your house will probably be colder than if you had left the temperature set point higher. Cold surfaces will make you feel colder—not just because of touch (conduction), but also because of radiation.

The strategy of saving energy by allowing your house to drop in temperature while it's unoccupied makes perfect sense. Programmable thermostats can "learn" how fast your house heats up and bring the temperature to the set point with little cycling. Also: Web-enabled thermostats, where you can access your home system from any Internet-connected computer, offer even more convenience for people with varying schedules.

Neil Smith • www.hvacquick.com

Pump Advice

Over the past three years, my wife and I have done significant upgrades to our home's passive systems (insulation, windows, siding, roofing, etc.). We've retrofitted lighting with better bulbs; replaced old, inefficient appliances with new, high-efficiency ones; installed a geothermal heat pump for space heating and cooling, and water heating; and we've added a grid-tied solar-electric system. Overall, our results have been great, and we're enjoying the home.

One energy hog that we have not addressed is the submersible well pump that is used for house and irrigation water supply. The pump is about 25 years old and will need to be replaced at some point. Can you help me with references, or even recommendations, on high-efficiency AC well pumps? I'd like to do some research in advance of the ultimate failure of the current pump.

Paul Speer • Vancouver, Washington

You are wise to plan ahead. As Murphy's Law dictates, your 25-year-old well pump will surely fail during a drought or a major holiday. If your pump is inefficient, either it is worn, or it was not optimally chosen by the original contractor. Pumps are like shoes—they come in many sizes. But pump suppliers often keep a limited number of sizes in stock, and don't always fine-tune their choice for the most efficient match to your specific situation.

Your well pump produces pressure using centrifugal force. It contains a stack of hollow discs called impellers. A specific amount of pressure is needed to produce the vertical lift and the pressure for distribution. To be on the safe side, a contractor often picks a model with an excess of impellers (usually called "stages"). A high number of impellers has high friction, and a lower efficiency than a pump that is optimally chosen for energy efficiency.

To optimize your pump choice, you'll have to specify the lift and flow requirements as best you can. You will need the data on your well. That may be from the original driller's record, or the record of any later testing that may have been done. If you don't have

Pumps should be matched as closely as possible to the lift and flow requirements of your application.

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the driller's record, contact your state office of groundwater resources. It is probably recorded there. You want to know the depth to the water-bearing portion of the well, and the recovery rate of the well. That's much more important than the overall depth of the hole, because the pump's performance is influenced by the water level in the well.

Also observe the pressure range that's used by watching your pressure gauge. (If you have more pressure than is needed, you can save money by adjusting the pressure switch to a lower setting.) Finally, estimate your maximum water flow requirements. For a single-family home, 10 gallons per minute (gpm) is a typical minimum.

To choose a pump, look at its performance curves (graphs), and pick one that works for your lift, pressure, and flow rate. If the efficiency curve is near its peak at that point, you have made a good choice. (It doesn't get much higher than 30% for conventional well pumps.) If your local pump contractor will not help you do this research, ask another one, or find the manufacturer's curves yourself. Efficiency does not vary much from one manufacturer to another, by the way. Favor those brands that local contractors install, since you'll likely be relying on them to troubleshoot the system, should the need arise later on. Given the choices between a "2-wire" or "3-wire" pump, get the 3-wire version. It requires a *much* lower power surge upon starting. A control box for your pump indicates that it is a 3-wire pump. (You will see four wires going to the well, because the ground wire is not counted.) There are also some new technologies in well pumps. You can eliminate the starting surge by using an electronic variable-speed pump (such as the Grundfos SQ and SQE series). People with very deep or low-production wells are using helical-rotor pumps (instead of impellers) to save a great deal of energy (examples are Grundfos SQF and Lorentz pumps). These technologies have been a breakthrough for off-grid wells that run on solar electricity only.

Before you replace your old pump, I suggest you make a simple observation. Stand near your water system so you can hear the pump operate. Open a faucet so the water pressure drops and the pump starts, and then close the faucet. Record the time it takes until the pump stops. Also, write down the pressures at which the pump "cuts in" and "cuts out." If the pumping time is less than a minute, you may have an undersized pressure tank; or the pump may be faulty or not adjusted (pre-charged) properly. You want to avoid frequent start/stop cycling because it requires more energy and reduces reliability.

On the other hand, if the pressure gauge just hangs there and it takes "forever" to reach the point where the pump stops, then you have a worn pump, or a pressure setting that's too high. You can find instructions on the Internet for servicing pressure switches and tanks. Most plumbers are not trained in pump service, so if you need help, it may be best to ask your local well service contractor.

You can download a short textbook on water system fundamentals at www.goulds.com/GP-Product-ID-300.asp. And finally, conserving water *is* conserving energy, so keep that in your whole-system perspective.

Windy Dankoff • Founder (retired), Dankoff Solar Pumps

write to:

asktheexperts@homepower.com

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2012 PV Module

by Brian Mehalic

The number of PV module brands, models, and manufacturers is staggering—so how can you choose the best ones for your system?

Modules are similar in technology, warranty, and price, but some will prove a better choice than others. Module prices have steadily decreased (see "...and Cost" sidebar), making them a smaller percentage of overall installed system cost—but modules are still expensive. And, as a long-term investment, reliable energy production is critical.

Unfortunately, there isn't any national board that certifies PV module quality *and* performance ratings. Though modules must meet Underwriters Laboratories (UL) 1703 standards for quality to be installed in systems subject to inspection, most of the performance data is provided by the manufacturers themselves. The California Energy Commission (CEC) attempts to fill this void through its list of approved equipment eligible to receive rebates.

We have reviewed the CEC database for compliant modules, collected their module data sheets, and verified the information with the module manufacturers. The result is a list of more than 830 modules from more than 50 manufacturers (available in its entirety at www.homepower.com). Manufacturers excluded were those without U.S. sales and distribution offices (customer service is important); those that only make thin-film modules (found mainly in large commercial and utility-scale systems); and modules smaller than 175 W (since larger modules are dominating the residential market).

For more details on deciphering module spec sheets, see "Understanding Module Specifications" in *HP145*. Keep in mind that specifications are subject to change—consult the manufacturer for the latest data.

The following information will help you make an informed decision about which module is right for your system. This is not an article about the "best module," nor even a "top 10" of modules, but rather a discussion of the features and specs of many modules that can work for different applications. Which module to select will depend upon the priorities of installers and end users, specific installation considerations, system applications, and expectations.

web extra

See our complete list of modules in the spreadsheet at **www.homepower.com/webextras**

Guide

Topher Donahue

STC & Rated Power

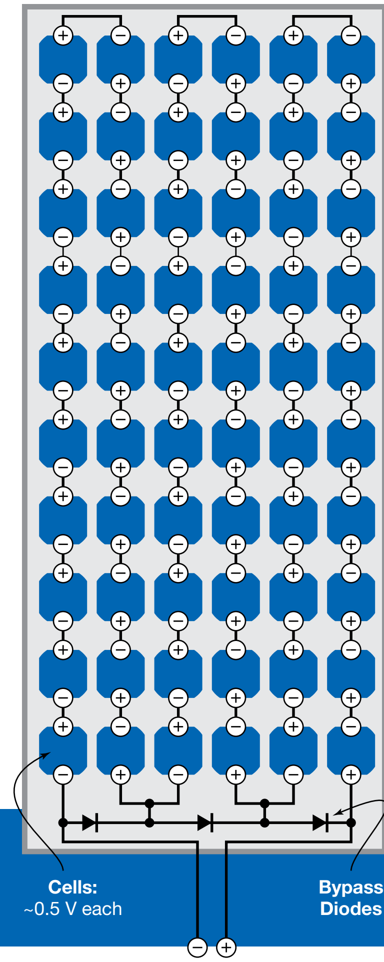
Module model names typically correspond to their rated power at standard test conditions (STC)—their output under 1,000 W/m2 of sun intensity and a 25ºC cell temperature. If there is a "225" in the model name, the module most likely has a nameplate rating of 225 W.

Module rated power has steadily increased over the years. Fifty-five W (and smaller) modules were once common; they gave way to 85, 110, and then 150 W modules. The trend continues, with most of the modules on our list rated at 200 W or greater (the average size of all the modules on the list is 236 W); only 30 on the list are rated at 300 W or more, and only three are rated at 400 W or more—all three are made by the same manufacturer, Grape Solar.

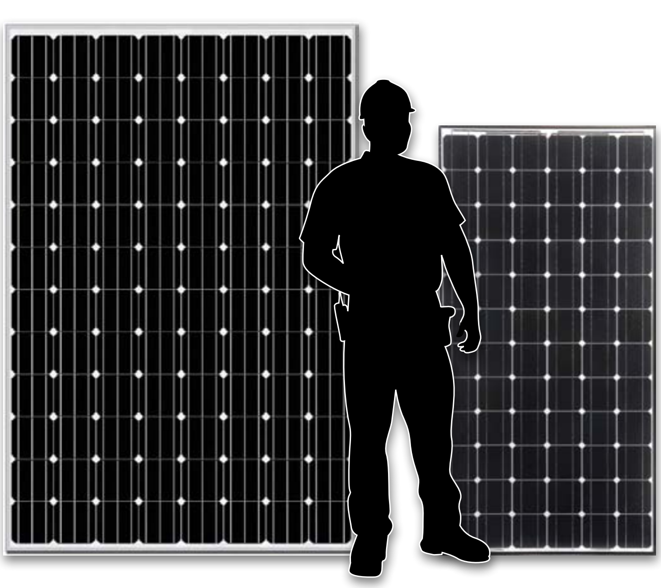
Distribution of Modules in Power Ranges

Power Range (W STC)	# of Modules
175 – 199	121
200 – 224	155
225 – 249	318
250 – 274	77
275 – 299	133
300 – 324	24
325+	6

PV Module Wiring



Module size is creeping up, with both pros and cons: A 96-cell, 410 W Grape Solar module (left) is almost 6.5 feet tall and more than 27.5 square feet, compared to a more common 72-cell, 230 W module (right) at about 17.5 square feet.



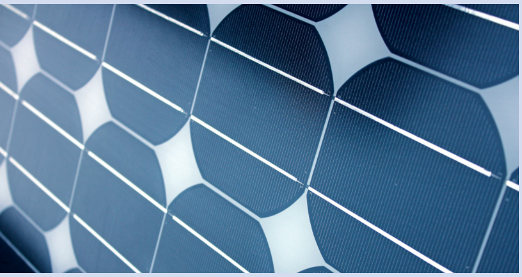
PV cell size determines the cell's amperage—the larger the cell, the more photons of sunlight it can intercept and the more current it can produce. Square 6-inch cells are the largest used in normal commercial production of crystalline silicon modules. Each cell can produce 8 amps or more, and each operates at about 0.5 Vmp. Wiring 96 of these cells together in series in one module produces approximately 48 V (96 × 0.5 VDC = 48 V), resulting in a 384 W module (8 A × 48 VDC = 384 W). The highest-power module listed on the table is 410 W, the result of 96, 8.15 A, 0.524 V cells wired in series for a module voltage of 50.3 Vmp.

Larger modules mean fewer modules to install for the same power output. Instead of 20, 200 W modules, 10, 400 W modules can be used. Fewer connections required between modules can improve system reliability. However, higher-voltage modules also can constrict system design options in residential applications, where arrays are limited to 600 VDC (see *Methods* in this issue).

Larger modules are a handful—the six largest modules on our list each measure 6 feet 5 inches by 4 feet 3.5 inches, weigh more than 78 pounds, and require two people to move. This compares to a typical 230 W module, which may be about 5.5 by 3.25 feet, and weighs about 45 pounds.

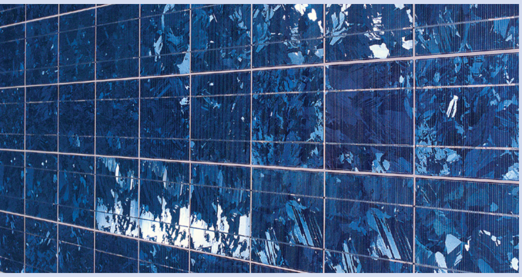
Module Type

Monocrystalline modules are the most efficient PV technology commercially available, and can convert sunlight to electricity at an efficiency of up to about 20%. Highly purified silicon and large amounts of heat are used to make a cylindrical ingot, from which cells are sliced. This cutting results in significant kerf waste, as some of the crystal is turned into dust. Additional cutting occurs when square cells are hewn from the middle of what is originally a round ingot. Diamond-like spaces between the corners of cells are typical of monocrystalline modules. But any blank space on the module's surface lowers its overall efficiency (W per ft.^{2}), regardless of how efficient the PV cell technology is.


Ben Root

Mono-crystalline

Polycrystalline modules have cells that are also cut, but from a large cast ingot that requires less energy to manufacture. However, cells produced this way are about 4% less efficient than monocrystalline. Often, the polycrystalline structure is evident in appearance, with cells having a much more heterogeneous pattern. Because the cells can be cut into squares, there is much less blank space between the cells, which can narrow the efficiency gap between mono- and polycrystalline modules. In some cases, it can be difficult to distinguish between the spacing between cells and the conductors that run up and down the cells, connecting them together.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Poly-crystalline

Other Available Cell Technologies

Mono a-Si (hybrid monocrystalline amorphous silicon) modules by Sanyo

UMG (upgraded metallurgical-grade silicon) made by Canadian Solar, which now offers a 25-year linear performance warranty (see below)

Thin-film silicon modules are not listed, as they are primarily used in utility-scale installations. They usually cost less per watt, but are much less efficient, and thus require more space and mounting structure to install an array of the same rated power.

Module Efficiency

When two modules of the same dimensions are exposed to the same sunlight intensity, the more-efficient one will yield more watts per square foot. Thus, module efficiency and rated power per square foot are closely related.

Watts per square foot is easy to calculate—divide the module's rated power by its dimensions in square feet. For example, a 250 W module that measures 40 inches by 65 inches (18.06 ft.^{2}, 40 in. × 65 in. ÷ 144 in.^{2}/ft.^{2}) produces 13.84 W per square foot (250 W ÷ 18.06 ft.^{2}).

Efficiency is calculated based on the nameplate power rating of a module, which what it produces when subject to 1,000 W per m^2, called "full sun." Calculating the module size in square meters means a ratio can be made to calculate efficiency (1 ft.^{2} = 0.0929 m^2). The 250 W module that makes 13.84 W per ft.^{2} is just a little less than 15% efficient:

18.06 ft.^{2} × 0.0929 = 1.678 m^2
250 W ÷ 1.678 m^2 = 149 W per m^2
149 W per m^2 ÷ 1,000 W per m^2 = 0.149 = 14.9% efficient

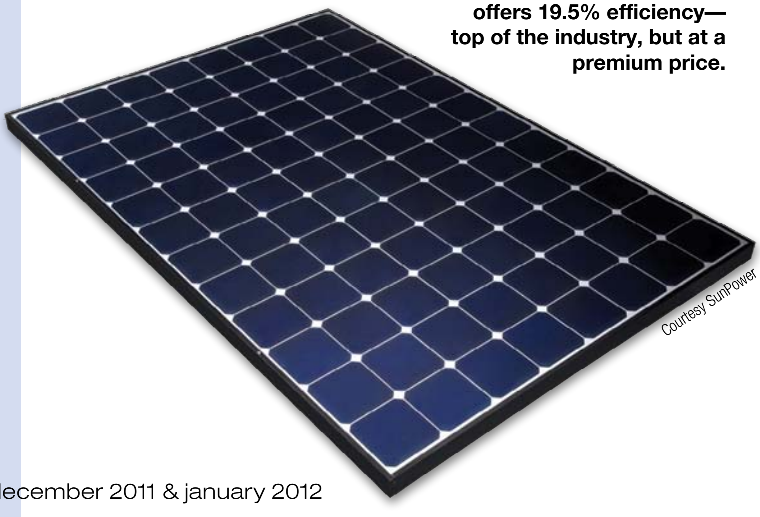
More than 530 of the modules on our list are at least 14% efficient; the field narrows to about 140 modules that boast at least a 15% efficiency rating; only 20 modules have an efficiency of 16% or more.

No matter how you slice it, SunPower modules are tops in both efficiency and watts per square foot. The company's monocrystalline silicon modules feature high-efficiency cells and use back contacts, eliminating the traces and conductors between cells that appear on the front of most modules and which block photons from sunlight. This translates to more surface area, more current, and more power per square foot.

Using efficient modules can be particularly effective when space is limited. However, if it costs too much, the bit of extra efficiency may not be worth it. Selecting modules based on cost—"dollars per watt"—frequently trumps efficiency when there is enough space for the array.

Selecting modules based on cost—"dollars per watt'" frequently trumps efficiency when there is enough space for the array.

SunPower's 318-watt module offers 19.5% efficiency—top of the industry, but at a premium price.


Courtesy SunPower

High-Efficiency Modules

Model	Cell Type	Module Effic. (%)
ecoSolargy www.ecosolargy.com		
SDM-170/(185)-72M	Mono	16.50
ECO315S156P-72	Poly	16.30
ECO310S156P-72	Poly	16.10
ECO260S156P-60	Poly	16.00
SDM-170/(180)-72M	Mono	16.00
Grape Solar www.grapesolar.com		
GS-S-410-Platinum	Mono	15.99
Lumos www.lumossolar.com		
LS205-72M-J	Mono	16.06
Sanyo www.us.sanyo.com		
HIT-N225A01	Mono, a-Si	17.80
HIT-N220A01	Mono, a-Si	17.40
HIT-215NKHA1	Mono, a-Si	17.10
HIT-210NKHA1	Mono, a-Si	16.70
HIT-205NKHA1	Mono, a-Si	16.30
HIT-195DA3	Mono, a-Si	16.10
SunPower www.sunpowercorp.com		
SPR-318E-WHT-D	Mono	19.50
SPR-315E-WHT	Mono	19.30
SPR-310E-WHT	Mono	19.00
SPR-308E-WHT-D	Mono	18.90
SPR-305E-WHT	Mono	18.70
SPR-230E-WHT	Mono	18.50
SPR-225E-BLK	Mono	18.10

Sanyo's HIT series offers a +10% (no minus) power tolerance.

Courtesy Sanyo

Power Tolerance

Unfortunately, the saying, "you get what you pay for" doesn't necessarily hold true when you're paying dollars per watt for PV modules. That's why you need to pay attention to power tolerance, the percentage that the actual power output of a module can vary from its STC rating.

For example, a 200 W module with a +/-5% power tolerance may produce anywhere from 190 to 210 W at STC. Product lines that are often differentiated in 10 W increments become blurred when the 210 W version of the same module may test between 200 W and 220 W. About 400 modules on our list have the most common power tolerance of +/-3%.

More than 350 of the modules listed have *positive-only* power tolerance, which means that the module will produce *at least* its rated power at STC, if not a little bit more. Nearly 75 on the list have a power tolerance of +5/-0% or better, including modules by Kyocera, Perlight Solar, Schüco, Solon, Suntech, Sanyo (+10/-0%), and Schueten Solar.

Product lines that are often differentiated in 10 W increments become blurred when the 210 W version of the same module may test between 200 W and 220 W.

High Power-Tolerance Modules

Model	Cell Type	STC Power (W)	PTC Power (W)	Power Tolerance
BP Solar www.bpsolar.com				
BP 4190T	Mono	190.0	172.0	+5/-0
BP 4185T	Mono	185.0	167.3	+5/-0
Kyocera Solar www.kyocerasolar.com				
KD245GX-LPB-ZT	Poly	245.0	219.1	+5/-0
KD240GX-LPB-ZT	Poly	240.0	217.3	+5/-0
KD235GX-LPB-ZT	Poly	235.0	212.6	+5/-0
KD215GX-LPU-ZT	Poly	215.0	194.4	+5/-0
KD210GX-LPU-ZT	Poly	210.0	189.8	+5/-0
Perlight Solar www.perlightusa.com				
PLM-305M-72	Mono	305.0	269.8	+5/-0
PLM-300M-72	Mono	300.0	265.3	+5/-0
PLM-295M-72	Mono	295.0	260.7	+5/-0
PLM-290M-72	Mono	290.0	256.1	+5/-0
PLM-255M-60	Mono	255.0	226.7	+5/-0
PLM-250M-60	Mono	250.0	222.1	+5/-0
PLM-245M-60	Mono	245.0	217.5	+5/-0
PLM-240M-60	Mono	240.0	212.9	+5/-0
PLM-185M-72 (PLM-5B-185M)	Mono	185.0	161.5	+5/-0
PLM-175M-72 (PLM-5B-175M)	Mono	175.0	149.8	+5/-0
PLM-290P-72	Poly	290.0	258.4	+5/-0
PLM-285P-72	Poly	285.0	253.8	+5/-0
PLM-280P-72	Poly	280.0	249.3	+5/-0
PLM-275P-72	Poly	275.0	244.7	+5/-0
PLM-270P-72	Poly	270.0	240.1	+5/-0

High Power Tolerance, cont.

Model	Cell Type	STC Power (W)	PTC Power (W)	Power Tolerance
Perlight Solar, cont. www.perlightusa.com				
PLM-240P-60 (PLM-6B-240P)	Poly	240.0	214.6	+5/-0
PLM-235P-60 (PLM-6B-235P)	Poly	235.0	210.9	+5/-0
PLM-230P-60 (PLM-6B-230P)	Poly	230.0	206.4	+5/-0
PLM-225P-60 (PLM-6B-225P)	Poly	225.0	197.4	+5/-0
PLM-220P-60 (PLM-6B-220P)	Poly	220.0	190.7	+5/-0
PLM-215P-60 (PLM-6B-215P)	Poly	215.0	187.3	+5/-0
PLM-210P-60 (PLM-6B-210P)	Poly	210.0	181.7	+5/-0
PLM-205P-60 (PLM-6B-205P)	Poly	205.0	176.2	+5/-0
Sanyo www.us.sanyo.com				
HIT-195DA3	Mono, a-Si	195.0	181.1	+10/-0
HIT-N225A01	Mono, a-Si	225.0	204.4	+10/-0
HIT-N220A01	Mono, a-Si	220.0	204.4	+10/-0
HIT-215NKHA1	Mono, a-Si	215.0	199.6	+10/-0
HIT-210NKHA1	Mono, a-Si	210.0	194.9	+10/-0
HIT-205NKHA1	Mono, a-Si	205.0	190.2	+10/-0
Scheuten Solar www.scheutensolar.com				
P6-54 205W	Poly	205.0	184.3	+10/-0
P6-54 200W	Poly	200.0	179.7	+10/-0
P6-54 195W	Poly	195.0	175.1	+10/-0
P6-54 190W	Poly	190.0	170.5	+10/-0
Schüco www.schueco.com				
MPE 230 PS 09	Poly	230.0	208.8	+5/-0
MPE 225 PS 09	Poly	225.0	204.1	+5/-0
MPE 220 PS 09	Poly	220.0	199.5	+5/-0
MPE 215 PS 04	Poly	215.0	197.0	+5/-0
MPE 210 PS 04	Poly	210.0	192.3	+5/-0
Solon www.solon.com				
SOLON Blue XT 285	Poly	285.0	254.9	+5/-0
SOLON Blue XT 280	Poly	280.0	250.3	+5/-0
SOLON Blue XT 275	Poly	275.0	245.7	+5/-0
SOLON Blue XT 270	Poly	270.0	241.1	+5/-0
SOLON Blue 235	Poly	235.0	210.6	+5/-0
SOLON Blue 230	Poly	230.0	206.0	+5/-0
SOLON Blue 225	Poly	225.0	201.4	+5/-0
SOLON Blue 220	Poly	220.0	196.8	+5/-0
SOLON Black XT 295	Mono	295.0	259.9	+5/-0
SOLON Black XT 290	Mono	290.0	255.3	+5/-0
SOLON Black XT 285	Mono	285.0	250.8	+5/-0
SOLON Black XT 280	Mono	280.0	246.2	+5/-0
SOLON Black 245	Mono	245.0	217.4	+5/-0
SOLON Black 240	Mono	240.0	212.8	+5/-0
SOLON Corvus 240	Mono	240.0	210.0	+5/-0
SOLON Black 235	Mono	235.0	208.2	+5/-0
SOLON Corvus 235	Mono	235.0	205.5	+5/-0
SOLON Black 230	Mono	230.0	203.7	+5/-0
SOLON Corvus 230	Mono	230.0	200.9	+5/-0
SOLON Corvus 225	Mono	225.0	196.4	+5/-0
Suntech www.suntech-power.com				
PLUTO245-Wde	Poly	245.0	222.0	+5/-0
PLUTO240-Wde	Poly	240.0	217.4	+5/-0
STP290 - 24/Vd	Poly	290.0	263.3	+5/-0
STP285 - 24/Vd	Poly	285.0	258.6	+5/-0
STP280 - 24/Vd	Poly	280.0	254.0	+5/-0
STP280 - VRM - 1	Poly	280.0	254.0	+5/-0
STP275 - 24/Vd	Poly	275.0	249.3	+5/-0
STP275 - VRM - 1	Poly	275.0	249.3	+5/-0
STP230 - 20/Wd	Poly	230.0	208.6	+5/-0
STP225 - 20/Wd	Poly	225.0	203.9	+5/-0
STP190S - 24/Ad(b)+	Mono	190.0	171.5	+5/-0

Nominal Operating Cell Temperature (NOCT)

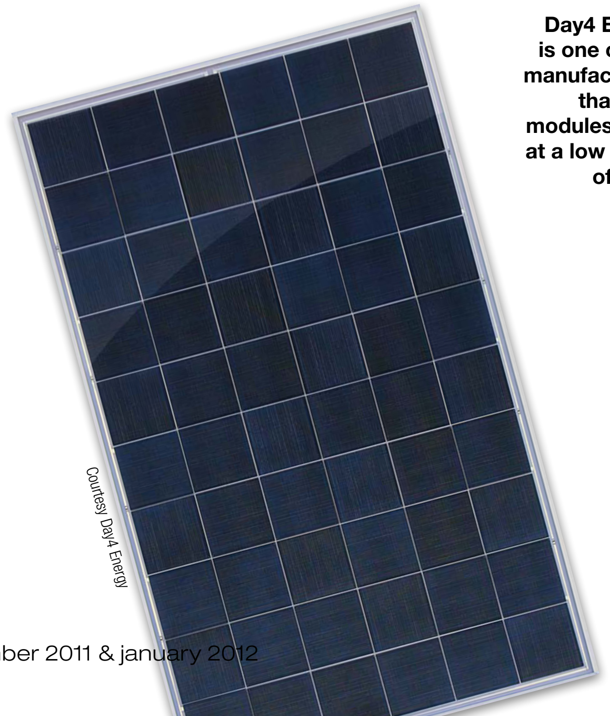
For better or for worse, the nameplate power rating of PV modules is based on standard test conditions. Efficiency is also essentially an STC rating, as it is a ratio to 1,000 W/m².

Unfortunately, the 25°C cell temperature used for testing is not a typical operating condition. In full sun, PV modules typically operate between 15°C and 30°C (approximately 60°F to 90°F) *above* the ambient temperature depending on how they are mounted (flush on a roof, on top of a pole, etc.). Thus, on a 25°C (77°F) day, cell temperature may be closer to 50°C (122°F). On a hot summer day, cell temperature can routinely approach or exceed 65°C (149°F). As cell temperature increases, voltage decreases. A decrease in voltage, at the same level of irradiance, means a proportional decrease in power.

A module's nominal operating cell temperature (NOCT) is measured with the module exposed to 800 W per m² irradiance, close to the weighted annual average irradiance a PV array is subject to; and at an ambient temperature of 20°C. This provides a better way to determine the effect of putting the modules in the sun—the lower the number (meaning the lower the cell temperature), the better.

About 330 modules on the list have a NOCT of 45°C or lower; the lowest NOCT is 43°C, and only 33 modules have this rating, mostly polycrystalline modules made by Day4 Energy, Astroenergy, DelSolar, and Schüco. On the other end of the spectrum, about 30 modules have an NOCT of 49 or 50° C. The cooler a cell can remain under high irradiance, the more power it can produce. Module current increases with temperature, but by a very small amount. As a result, the overall effect of increased cell temperature is an inversely proportional reduction in power output. Side by side, and all else being equal, a module with a 43°C NOCT should produce about 3% more power than a module with a 50°C NOCT.

...the overall effect of increased cell temperature is an inversely proportional reduction in power output.



Courtesy Day4 Energy

Day4 Energy is one of four manufacturers that have modules rated at a low NOCT of 43°C.

Temperature Coefficients & PTC-to-STC Ratio

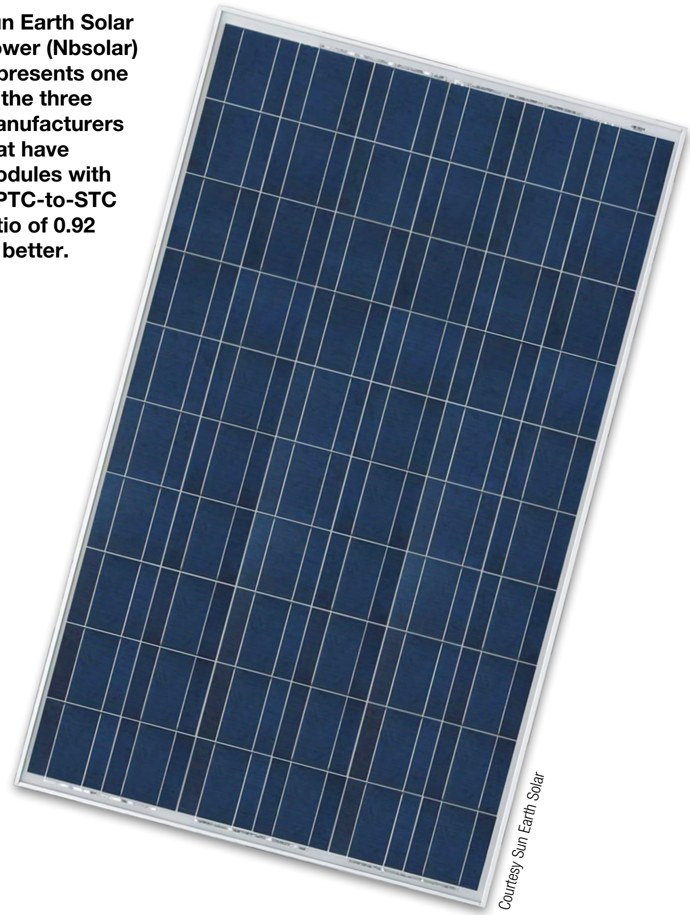
Module spec sheets include data on temperature coefficients of voltage, current, and maximum power (Pmp), specifying how much those characteristics are impacted by changes in temperature. Temperature coefficients (Tk) of voltage are negative—for each degree Celsius that cell temperature exceeds 25°C, the open-circuit voltage (Voc) and maximum power voltage (Vmp) drop by a certain amount, either given as a millivolt value or as a percentage. (The average temperature coefficient of open-circuit voltage [TkVoc] for all the modules on the list is -0.33%/°C). Temperature coefficients of current, while positive, are negligible.

Also a negative value, the average temperature coefficient of maximum power (TkPmp) for all the modules on the list is -0.45%/°C. The closer to zero the coefficient is, the less power the module will lose when operating at real-world cell temperatures. Nearly 100 modules on the list have a temperature coefficient of power of -0.40% or better; only 19 have a TkPmp of -0.37% or better, including modules from Sanyo, Schüco, Grape Solar, and MAGE Solar.

The NOCT cell temperature is used with the maximum power temperature coefficient to calculate a module's PVUSA test conditions (PTC) rating. All modules on the CEC list are required to have independent testing done to confirm their NOCT and TkPmp. PTC module power ratings will always be lower than their STC ratings; some states and utilities use the PTC rating to determine up-front rebate incentive payments, and PTC ratings are also used as a more accurate portrayal of real-world performance.

Because modules are typically purchased based on dollars per watt, the closer the PTC rating is to the STC rating, the more power the module should produce, all other conditions being equal. More than 230 modules on the list have a PTC-to-STC ratio of 0.90 or better. For example, that means that a 200 W STC module has a PTC rating of at least 180 W. Just 20 modules have a PTC/STC ratio of 0.92 or better, including modules from Sanyo, Sun Earth Solar Power (aka Nbsolar), and SunPower.

Sun Earth Solar Power (Nbsolar) represents one of the three manufacturers that have modules with a PTC-to-STC ratio of 0.92 or better.



Courtesy Sun Earth Solar

High PTC-to-STC Ratio Modules

Model	Cell Type	STC Power (W)	PTC Power (W)	PTC/ STC Ratio
Sanyo www.us.sanyo.com				
HIT-N220A01	Mono, a-Si	220	204.4	0.9291
HIT-195DA3	Mono, a-Si	195	181.1	0.9287
HIT-215NKHA1	Mono, a-Si	215	199.6	0.9284
HIT-210NKHA1	Mono, a-Si	210	194.9	0.9281
HIT-205NKHA1	Mono, a-Si	205	190.2	0.9278
Sun Earth Solar Power www.nbsolar.com				
TPB156x156-54-P, 185W	Poly	185	171.6	0.9276
TPB156x156-54-P, 180W	Poly	180	166.9	0.9272
TPB156x156-60-P, 205W	Poly	205	189.4	0.9239
TPB156x156-60-P, 215W	Poly	215	198.6	0.9237
TPB156x156-60-P, 200W	Poly	200	184.7	0.9235
TPB125x125-72-P, 175W	Poly	175	161.6	0.9234
TPB156x156-60-P, 210W	Poly	210	193.9	0.9233
TPB125x125-72-P, 180W	Poly	180	166.2	0.9233
TPB156x156-60-P, 220W	Poly	220	202.9	0.9223
TPB156x156-60-P, 225W	Poly	225	207.5	0.9222
TPB156x156-60-P, 230W	Poly	230	212.1	0.9222
SunPower www.sunpowercorp.com				
SPR-318E-WHT-D	Mono	318	292.9	0.9211
SPR-315E-WHT	Mono	315	290.0	0.9206
SPR-310E-WHT	Mono	310	285.3	0.9203
SPR-308E-WHT-D	Mono	308	283.4	0.9201
SPR-305E-WHT	Mono	305	280.6	0.9200

Because modules are typically purchased based on dollars per watt, the closer the PTC rating is to the STC rating, the more power the module should produce, all other conditions being equal.

Courtesy Silicon Energy

Silicon Energy's power warranty is 15 years at 90% of rated output, and 30 years at 80%.

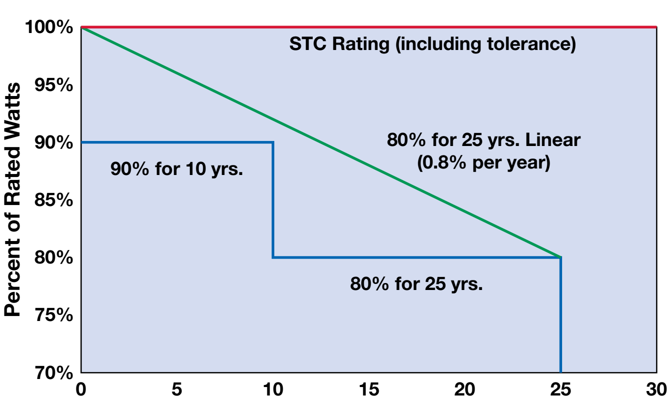
Warranty

Every PV module carries two distinct types of warranty—a materials (or workmanship) warranty and a power warranty.

The materials warranty covers the module's parts and workmanship. It is critical to read the fine print, but a materials/workmanship guarantee generally provides service or replacement of defective modules by the manufacturer. Some of the limitations are based on the parts that module manufacturers use to assemble modules, such as quick-connects and sealed junction boxes, which have their own warranties from their own manufacturers. Of the more than 830 modules on the list, 500 carry at least a five-year materials/workmanship warranty and about 250 are at 10 years.

A module's power warranty guarantees that the module will produce a certain percent of its rated STC power (Pmp, minus any power tolerance) for a given period of time. A common warranty is 90% of rated power for up to 10 years and 80% for up to 25 years. Silicon Energy and MAGE Solar offer 30-year, 80% rated-power warranties—tops on the list. (Silicon Energy also offers a best-of-list 15-year, 90% rated-power warranty.) All of the modules that have 10-year materials warranties have at least 25-year, 80% rated-power warranties.

Typical Power Warranties



*Blue line is worst case for a stepped power warranty

...and Cost!

Compare all the stats you want: the majority of consumer decisions are made first and foremost on price, and module prices have decreased for the last several years. Global fluctuations in demand have and will likely continue to occur—entire nations have implemented, adjusted, and/or repealed various incentives for grid-connected PV systems. Furthermore, it takes time for manufacturers to scale up to meet demand. Combine these two factors, and the result is a market where supply can, and often does, exceed demand.

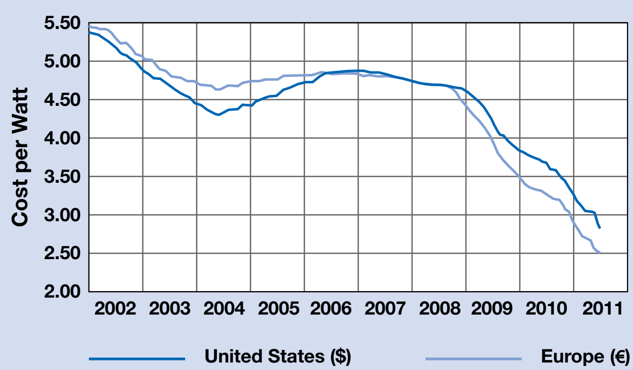
Solarbuzz is a company that tracks PV industry price trends (see www.solarbuzz.com). Their retail module price index shows modules at an all-time low of $2.65 per W as of September 2011, around half of what modules cost at the start of 2002. These are retail prices, with distribution and installer markups included, and do not take bulk pricing into consideration. Many modules are available for less than $2 per W, with some below $1.50 per W.

Many utilities and states are reducing rebates for PV systems. Fortunately, this corresponds with all-time-low module prices, meaning system costs are decreasing ($ per installed watt) as well. As in any market, prices will continue to fluctuate based on supply, demand, and government support of the industry.

When thinking about purchasing cheap modules, realize that you might get what you pay for. Quality matters, and often it becomes a factor over time. Consider how long your module manufacturer has been around. Reputation must be earned, and word of mouth has impact.

Module prices aren't part of this list because, like any commodity, price isn't fixed, but rather depends on who you know, how many you buy, and what overall manufacturing price trends are.

Module Price Index



Data Courtesy Solarbuzz

Module prices aren't part of this list because, like any commodity, price isn't fixed, but rather depends on who you know, how many you buy, and what overall manufacturing price trends are.

A longer warranty implies better protection for the module owner. Of course, it is important to consider the company that is offering the warranty, especially with so many new companies in the market.

About 75 modules on the list have 25-year *linear* warranties, including modules from Scheuten Solar, SCHOTT Solar, Siliken, SolarWorld, Suntech, Tianwei New Energy, Trina Solar, and Upsolar. Compared to a percentage warranty (where a module at year 11 could only make 80% rated power and still meet the warranty), a 25-year, 80% linear warranty means the module output is warranted to not decrease more than 0.8% per year—at year 11, the most it could have decreased would be 8.8%.

A longer warranty implies better protection for the module owner. Of course, it is important to consider the company that is offering the warranty, especially with so many new companies in the market. Additionally, testing to verify power production and pursuing power warranty claims can be a difficult and time-consuming procedure.

SolarWorld and other companies offer linear warranties that allow a yearly percentage decrease in output over the warranty period.

Courtesy SolarWorld

Access

Brian Mehalic (brian@solarenergy.org) is a NABCEP-certified PV installer and ISPQ-certified PV instructor. He has experience designing and installing both PV and solar thermal systems, and is a curriculum developer and instructor for Solar Energy International.

PV PERGOLA

by Mike Taylor

My solar career was launched 10 years ago, when I helped start Minnesota's first PV incentive program (see "A Tale of Two States: Small Solar Rebates—Steady Success," *HP111*). Today, I do market research on electric utility engagement in the solar industry for a national association. Ironically, in all of those years, I didn't have the right situation to install my own PV system. But after moving to northern Utah when my wife got a new job—and buying what I hope is our last home—it was finally time to make a solar commitment.

My goals were simple: maximize solar's impact on our electricity consumption, minimize the physical size of the system, and design an attractive system. It was time to apply 10 years of advising others to my own PV installation.

Design & Planning

The common siting choices did not work for our house: the backyard is significantly shaded and in a flood plain; and the roof is moderately shaded and flat, creating snow and wind-loading issues that I wanted to avoid. Using Solmetric's iPV iPhone app (see "Siting App" sidebar), I analyzed the shade in the backyard (40%–50% shading annually), the roof (15%–25% shading), and the front yard (4%–6% shading) which was shown to be the sunniest location. Although my house is located in a residential neighborhood, it sits 125 feet back from the street and the front yard contains 11 fruit trees, a 1,000-square-foot vegetable garden, and the rest has perennial flowers—it's not your typical lawn.

Courtesy Josh Kordecky/Alpenglow Solar (2)

Once the structure was completed, the PV rack rails were installed.

I designed a garden-appropriate wooden pergola for the array, based on a photo I found online. Unlike an industrial-looking pole mount or a metal-framed ground mount, the wood matched the existing fence and allowed us to walk under and through the structure (rather than around), softening the visual impact from the street and maintaining usable space underneath it. The pergola was built using Douglas fir, and to ensure longevity, the main wooden posts were set in slightly elevated Simpson brackets attached to the concrete footers, which keeps them well drained and away from soil contact. The entire pergola was sealed using Penofin, a UV-resistant stain, and all horizontal joints and penetrations were sealed with caulk.

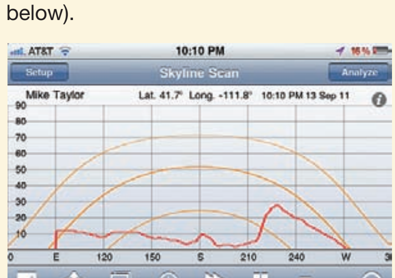
I wanted to keep the pergola as small as possible but have an array big enough to have a measurable impact on our electricity use. That meant focusing on the modules with the highest power density—the greatest number of watts per square foot. I narrowed it down to SunPower SPR monocrystalline modules with rated efficiencies of about 19% and a power density of up to 18 watts per square foot—the most efficient modules on the market.

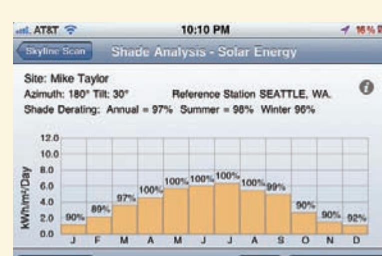
I compared different quantities of modules in various landscape and portrait configurations, looking at both the estimated annual performance and the resulting size of the pergola. I wanted to make sure we would offset at least 50% of our consumption but also not get too close to 100%—right now, the utility pays for excess annual generation at half the retail rate. I resurrected my high school trigonometry to play the tilt angle against the height and depth of the structure, including making sure that the fruit trees behind the pergola wouldn't be shaded from May through October. I'm not an engineer and just overbuilt to cover any possibility for wind and snow loads, figuring the city engineer would tell me if the structure wasn't up to par. My final design was nine 230 W modules, placed in a landscape orientation three wide and three high, and tilted at 30°.

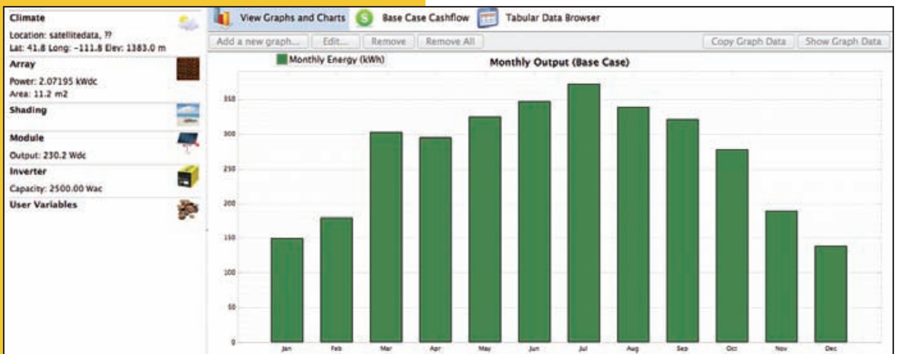
One problem I found was that wiring the nine modules in series created the potential for high open-circuit voltages in the winter. Only a few inverters will accept 550 volts and closely match my 2 kW array size. SunPower modules also require a positive ground, which the inverter must match (most equipment uses a negative ground). Kaco's Blueplanet 2502xi inverter was slightly oversized for my system, but would work fine within these requirements. I could have chosen microinverters, and a number of people in my area are doing so, but I'm not yet convinced of their longevity in the field under harsh temperature and moisture conditions—it all depends on your risk tolerance for using newer technologies.

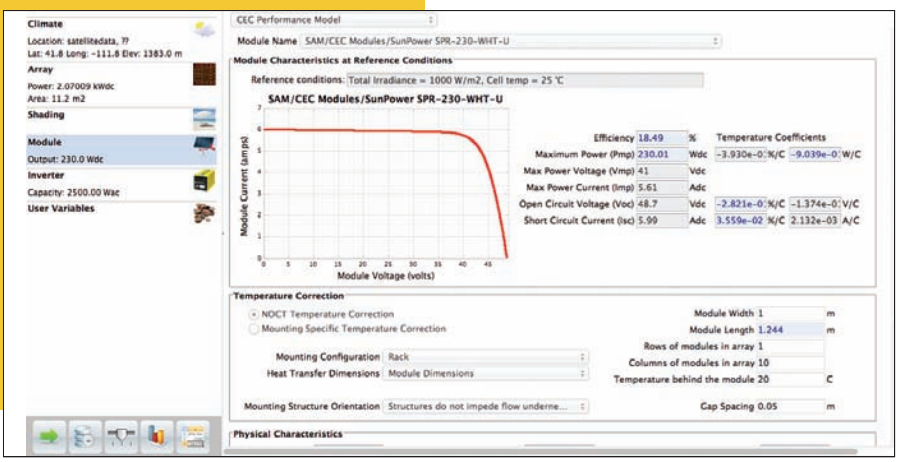
An Inexpensive Siting App

Solmetric's iPV iPhone app ($39.99) uses the iPhone's camera, compass, and inclinometer as the user traces the outline of anything (mountains, trees, buildings, etc.) on the horizon panning from east to west. It generates a two-page report with monthly shading and performance estimates, the latter using a database of PV modules and inverters. One drawback is that it can't save more than one location for future reference, so it can't compare two locations. Another is that you have to choose from 200+ reference U.S. cities, which may or may not be close to your site. But for the price and convenience, it's a good tool for homeowners. I've used it again for site assessments with friends who became interested in a system after seeing ours (scans below).









Screen shots from NREL's SAM modeling software.

Pergola Construction & Project Costs

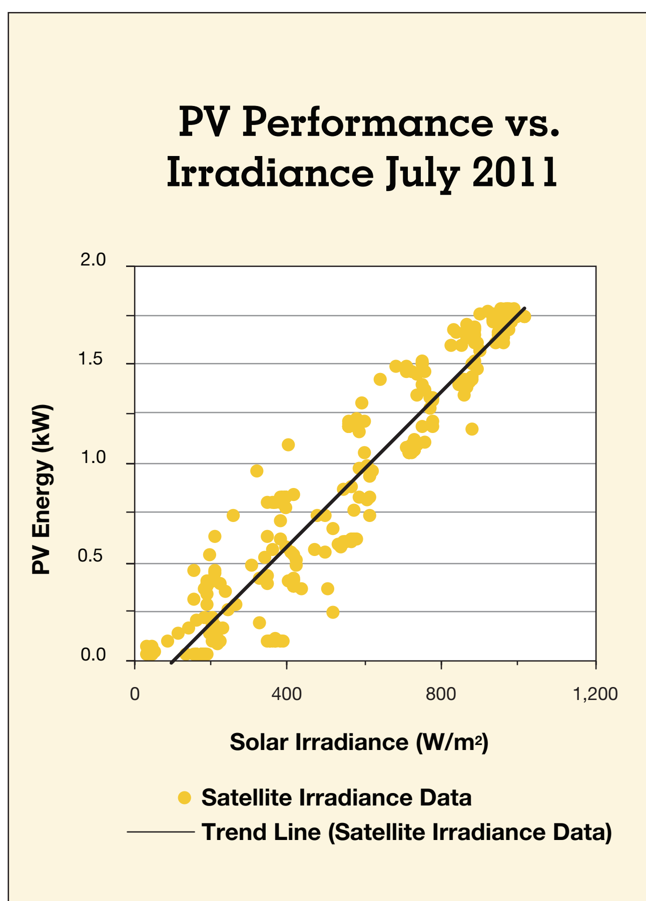
The construction phase was easier than the permitting. A few months earlier, we discovered that our main water line was leaking and a three-foot-deep trench would need to be excavated from the street to the house, passing next to the pergola location. As part of that process, we laid conduit in the same trench for the 125-foot run to the garage, where the inverter was to be located. A local contractor took care of building the pergola, and Alpenglow Solar handled the PV installation in a couple of days. The local municipal utility replaced the existing analog meter with a bidirectional electronic meter at no charge and inspected the system the next day, finding no issues.

Best Laid Plans...

After submitting my building permit application, the city planning department called. Because the array on the pergola would be electrically connected to the home, they were lumping my project in the "accessory structure" category, which includes garages and workshops. Unfortunately, the city's land development code (LDC) didn't allow them in front of a home—only beside or behind.

Absurdly, the pergola could have been built without any permit if it wasn't electrically connected to the house—it was small enough not to trigger the requirement. Instead, I had to file for a variance, which included paying more money. The city sent a variance meeting notice to my neighbors, and published it in the local newspaper and on the city website. In preparation for the meeting, I read the entire LDC and wrote a five-page briefing on why I felt they should approve the variance, which ranged from alignment with state and city energy policy goals, to perceived inconsistencies with the code itself, to an analysis of why the roof and backyard (and cutting down trees) weren't reasonable alternatives.

After I submitted my briefing, the city planner called a few days before the variance meeting to negotiate. They would call it a "garden structure" if I added some lattice and planted some grape vines to hide the underside of the PV modules from the street, making its primary purpose about the garden and not the solar. I don't blame the city—they need to have a consistent decision-making process—it's just that if you're the first one to do something, it can take longer and cost more. Six weeks and $542 later, I had my permit and could start building.



Data Collection & Management

I'm a data geek—for example, I have spreadsheets of all of my utility bills going back 10 years for three different homes. Using the previous owners' bills for our Utah home, I calculate that we've reduced electricity consumption by about 50%—with minimal investment. I wanted to keep an equally close watch on our PV system's performance.

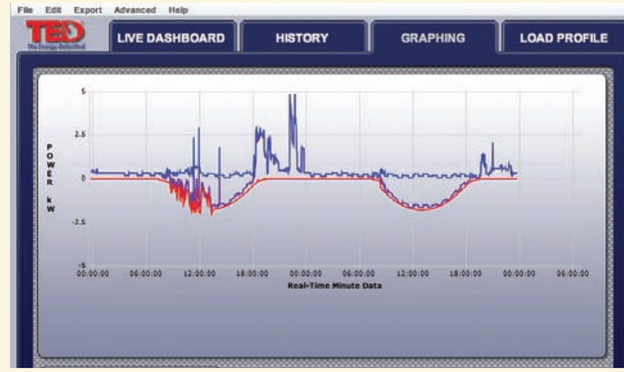
If not included in the price, inverter manufacturers' data management options can cost anywhere from $250 to $500 (if a fixed cost), or $5 to $10 per month (if an ongoing charge). There are also third-party (non-inverter) options that can set up monitoring for similar fixed or annually recurring charges. If the data is important to you and you don't want to DIY, buying one of these options may be worth the cost. While I was researching options, my PV installer mentioned that one of his clients was using The Energy Detective (TED) and was happy with it. After some research, I decided to try it.

Depending on which model you choose, the TED 5000 series will monitor up to four electrical circuits—your home's total consumption; subcircuits like your air-conditioning or workshop; PV generation; etc. I chose the TED 5002-G to monitor two circuits, one for PV and one for consumption.

The TED package included two current transformer clamps (CTs) with measuring transmitting units (MTUs) to measure the current and voltage in the wires, and a gateway to collect and display the data. Physical installation was not difficult—the CT clamps wrap around the positive and negative wires and connect to the small MTU boxes. The MTU boxes were then wired into the two-pole breaker serving the PV disconnect (outside) and the whole-house disconnect (inside the circuit breaker box). I plugged the receiving unit into the wall outlet closest to our Internet router and connected them with an Ethernet cable.

The MTU sends the data through the house's electrical circuits to the receiving unit. The data is accessible either with an optional table-top display and/or on an intranet web page through your Internet router using software embedded in the receiving unit. I've also set up an option to view the web page outside my house intranet by forwarding the IP address through my router's firewall.

The TED dashboard displays a wide array of information and system data.



A TED graph showing system power output on a cloudy day (left) and sunny day (right). The red line represents solar, which logs as negative values. Consumption is shown in blue and logs as positive values. Purple is the net between the two.

The TED software has a variety of options for customizing the online display and data collection, and for downloading your data to a spreadsheet for analysis. You can also link your account to a number of free, third-party energy Web services, such as myEragy, People Power, or others. These third-party options sometimes have better graphical displays than TED and can analyze and e-mail reports or alerts on your electrical usage. They are also easier than setting up your own IP address forwarding.

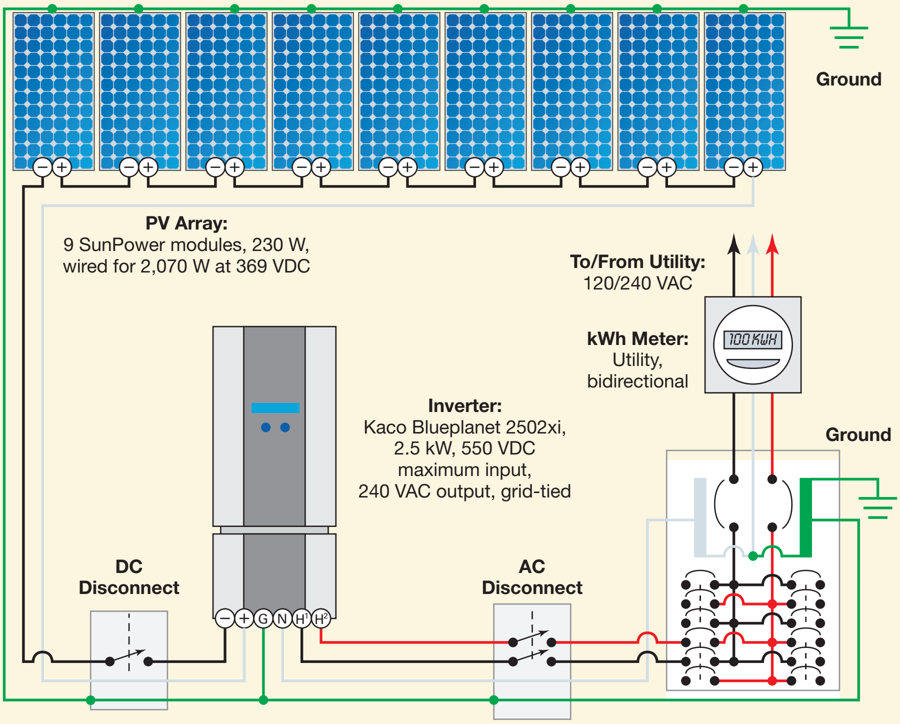
With either option, you can access your data anywhere in the world that you have Internet access. This can be as much for show as anything, but two practical applications include checking for power outages if you're away from the house for an extended period of time or troubleshooting system or data errors remotely.

The TED device has been fairly accurate. I've compared the consumption data to my utility meter measurements on my monthly bills and, so far, the average difference is about 1.5% over a year.

I'm satisfied with TED's performance, but some people report problems with getting the data from their transmitting units to their receiving units—other electrical appliances may cause interference on the electrical wire. Moving the receiving unit to another electrical outlet can solve the problem. Unexplained data spikes or hour-long data flat lines occasionally show up in our system, though the overall impact is minimal.

As a data-collection nerd, one major problem I had was multiday missing data after trying to test one of the third-party data management options. I didn't notice the problem until later and then reset my TED device to fix it. Thankfully, a colleague at Clean Power Research, a company I collaborate with (see Access), provided me with hourly satellite solar irradiance data from their SolarAnywhere data service for my area for July 2011. I created a scatter graph using this data and my previous PV data to create a trend-line (see graph on previous page) and then applied the trend-line formula to the irradiance data during the data gap to recreate it. For consumption, I simply averaged my daily usage for the few days before and after the gap and called that close enough.

Taylor Batteryless Grid-Tied PV Pergola System



Note: All numbers are rated, manufacturers' specifications,or nominal unless otherwise specified.

AC Service Entrance: To 120/240 VAC loads

This Kaco inverter has the required input voltage, closely matches the array size, and can work with positive-ground SunPower modules.

The TED monitoring system uses input from transducers clamped around the cables at the main breaker box.

Courtesy Alpenglow Solar (2)

Tech Specs

Overview

System type: Batteryless, grid-tied solar-electric

Location: Logan, Utah

Solar resource: 5.16 average daily peak sun-hours

Record low temperature: -30°F

Average high temperature: 88°F

Average monthly production: 253 AC kWh

Average monthly consumption: 320 AC kWh

Utility electricity offset (Sept. '10–Aug. '11): 79%

Photovoltaic System Components

Modules: 9 SunPower SPR-230-WHT-U, 230 W STC, 41.0 Vmp, 5.61 Imp, 48.7 Voc, 5.99 Isc

Array: One, 9-module series string, 2,070 W STC total, 369 Vmp, 5.61 Imp, 438.3 Voc, 5.99 Isc

Array installation: Unirac SunFrame rails installed on south-facing roof, 30° tilt

Inverter: Kaco Blueplanet 2502xi, 2.5 kW rated output, 550 VDC maximum input, 200–450 VDC MPPT operating range, 240 VAC output

System performance metering: TED 5002-G

Major Load Information

Space Heating: Natural gas, forced-air furnace

Cooling: Electricity, central air (though used only about five days per year)

Water Heating: Natural gas, storage tank heater (i.e., conventional)

Cooking: Electricity, range, and oven

Clothes Drying: Natural gas

Dishwasher: Electricity

Refrigeration: Electricity

Chest freezer: Electricity

Mike Taylor

Once the rails were up, the modules were mounted in a landscape configuration.

Taylor System Costs

Item	Cost
9 SunPower SPR-230 modules	$7,245
Pergola labor & materials	4,483
PV system Labor	4,320
Kaco Blueplanet 2502xi inverter	1,774
Trenching & conduit	1,441
Miscellaneous (rack, electrical, etc.)	1,168
Permits	542
TED data monitor	280
Total System Cost	**$21,253**
Federal tax credit (30%)	-$6,292
State rebate ($2 per W)	-4,200
State tax credit (25%, $2,000 max)	-2,000
Federal income tax (on rebate)	1,050
Total Cost	**$9,811**

The system cost more than most—the permits, a portion of the trenching and conduit, building the pergola, and using the premium modules all added to the costs. But the state had a rebate program and a tax credit that helped defray the costs. The system is net metered (retail rates average 9.5 cents per kWh), with an annual true-up—any surplus electricity the system generates is paid out each April at 5 cents per kWh. We pay a minimum $3.80 per month utility charge, regardless of our consumption, to cover the utility's fixed costs.

But I had to wait until tax time to take advantage of the state and federal tax credits, and the state rebate was taxable on my federal income taxes. This isn't ideal, but if you tax the rebate you don't have to subtract it from the total system costs when you calculate the 30% tax credit. State rebates are generally taxable; utility rebates are generally not. (Consult your tax accountant for specifics.)

The incentive paperwork was manageable, but I had to apply separately to the two state programs, one for the rebate program and one for the tax credit program. There is also no renewable energy credit (REC) market in Utah, and exporting the RECs to another state is cost-prohibitive, but can be a

revenue stream available in some other states.

Our existing homeowners insurance policy provides $15,000 in coverage for external structures like garages and it put the PV pergola in the same category. Since the pergola and the garage are separated by 100 feet, the risk of catastrophes on both at the same time is small, so we felt it unnecessary to increase protection.

What's the payback? For me, solar energy is a hobby (which aligns with my ethics) like someone else's fishing boat or swimming pool—things that aren't subjected to cost-benefit analyses. Unlike fishing or swimming, however, solar is a hobby that generates some income in the form of savings on our utility bill.

In strictly economic terms, the rate of return for your PV system depends on three things—solar resource (in Utah, it's good); electricity prices (Utah: low); and state policies or incentives (Utah: high then, but now low). In our particular situation, it's a low rate of return (but so is my savings account rate these days). With the combination of incentives I received and the possibility of low-interest rates on a mortgage refinance, the system would have nearly evened out—i.e. annual loan costs were only slightly higher than the annual electricity savings—if I had chosen that option.

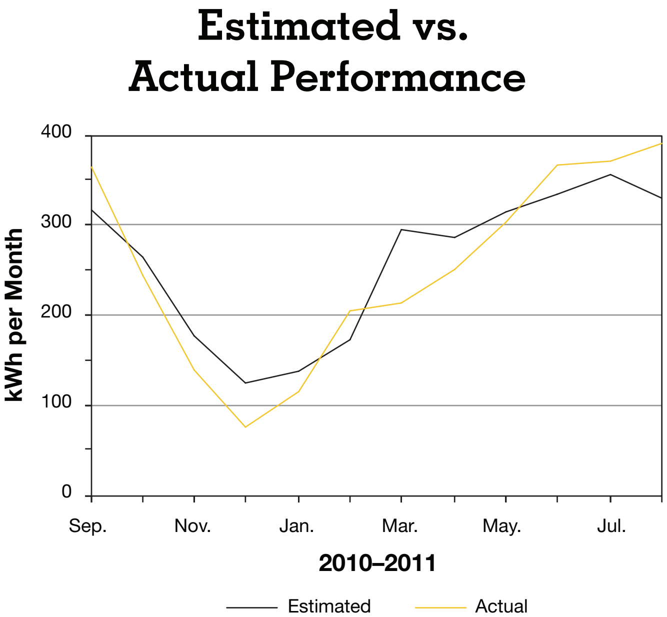
Mike Taylor

The city's planning department allowed the PV pergola by terming it a "garden structure."

Performance

The system's performance met my software estimates fairly closely. Before installing, I modeled system performance using the National Renewable Energy Laboratory's (NREL) Solar Advisor Model (SAM) software. Unlike NREL's PVWatts or other web-based calculators, SAM can perform a more detailed analysis using specific system components and historical irradiance data from near my home. This software is not easy for the layperson to use, but if you are willing to learn, it is not insurmountable.

I took SAM's output, applied the monthly shading estimate from the Solmetric app, and then compared that to the actual performance. Our system's yearly generation was about 2% less than SAM predicted, which I consider quite close. Month-to-month variations from the estimate have ranged from -39% to +19%. Any number of factors could explain the variation—dirty panels, snow cover, winter pollution, wiring losses, solar radiation different from the average, etc. But from May to August 2011, I had four straight months of negative meter readings, essentially turning the meter clock backward—a satisfying feeling.



Take-Aways

Other than the city permitting process, the design and installation went smoothly. Because of my solar experience and the unique design and location, I took on a burden that the average homeowner shouldn't need to—the installer normally will design the system, apply for the permits, handle the interconnection application and incentive paperwork, get utility interconnection approval, and perhaps even set up the data monitoring system. Just remember that the lowest bid usually won't give you the best service. Make sure you clearly discuss what is and isn't included in the package price with your proposed installer.

Access

Mike Taylor (mptaylor123@gmail.com) is the research director for the Solar Electric Power Association (www.solarelectricpower.org) in Washington, D.C. A thermal energy audit and retrofit, with solar space or water heating, is his next personal energy challenge.

Alpenglow Solar • www.alpenglowsolar.com • PV installer

Solar Advisor Model (SAM) • www.nrel.gov/analysis/sam • Performance estimator

Solmetric iPV • www.solmetric.com • Shading analysis iPhone app

SolarAnywhere • www.solaranywhere.com • Satellite irradiance data

Database of State Incentives for Renewables and Efficiency • www.dsireusa.org • RE incentives

System Components:

Kaco New Energy • www.kaco-newenergy.com • Inverter

SunPower • www.sunpowercorp.com • PV modules

The Energy Detective • www.theenergydetective.com • Monitoring

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Microhydro Systems

Pro Advice for End Users

Interviews by Ian Woofenden

Home-scale microhydro-electric systems can give the best renewable bang for the buck. With the right situation and implementation, you can have a low-impact, low-maintenance, reliable system that supplies clean energy over the long haul.

Courtesy SunWater Power Systems

As with any renewable energy system, the dividing line between a dream and a working project includes education, experience, and expertise. When dealing with something as powerful and fragile as a flowing watercourse can be, it's important to find people who have "been there and done that."

Here, 12 hydro experts share the perspective of decades of hydro experience and wisdom. The group's experience includes off-grid hydro living; system design, specification, and installation; engineering, consulting, and contracting; and equipment design and manufacturing. Read on and consider whether you have the right site, situation, and motivation to pursue energy from falling water.

Q: What's the first step to identifying a good hydro site?

The two primary components of hydro-electric power are head (vertical drop) and flow. A good site needs a combination of these two. Higher head sites may be more cost-effective to tap, since you can use smaller pipe and less water. Ideally, you want water tumbling down the hillside—this is one sign of a potential hydro site. Water that is dead "flat" won't do much for you—if there is no head, there is no power.

If you double the head, you double the power available. The same is true if you double the flow. Higher head is the least expensive way to generate more power. Increasing the head increases the water pressure, which requires more robust components, but doesn't add significant cost to the turbine. On the other hand, more flow requires a physically larger turbine to handle the mass. As a general rule, higher flow requires more steel, which drives up the cost. A good home-scale system might have a vertical drop in the range of 40 to 200 feet.

A steady flow from a perennial stream is ideal. Seasonal streams that suffer wide fluctuations in flow linked to wet and dry seasons can be designed for, but require compromises in the design parameters.

Look for a good site rather than the closest site. With high-voltage transmission coupled to modern MPPT controllers and grid-connected inverters, wire cost for longer distance is often not the biggest issue. Other good attributes are a convenient and environmentally friendly intake site, easy access and permitting, and a relatively short pipe run.

Before you even consider hydro sites, realistically assess your energy needs. A common error is overestimating actual electricity needs. We live in a wasteful society, and use a lot more energy than is necessary due to inefficient appliances

and lack of attention to conservation. The trouble with overestimating your energy needs is that it makes systems larger and more expensive, and often such large and expensive projects have a way of not getting done. In a hydro system, building a system for a wasteful home may mean using more materials and taking a larger portion of the stream flow.

Q: What types of water sources are not appropriate for microhydro systems?

Because available power comes from head and flow, water sources with little flow or little head will not work. Flat-water rivers are difficult or impractical to capture energy from, which is why we see few if any products on the market for this type of site. Large, gently flowing rivers like the Amazon, Nile, and Mississippi are generally unsuitable for any microhydro systems other than paddle-wheel floating designs that seldom generate more than a token amount of power. A "low-head" site typically needs to dam the whole river or divert a large amount of water in a canal to create some head.

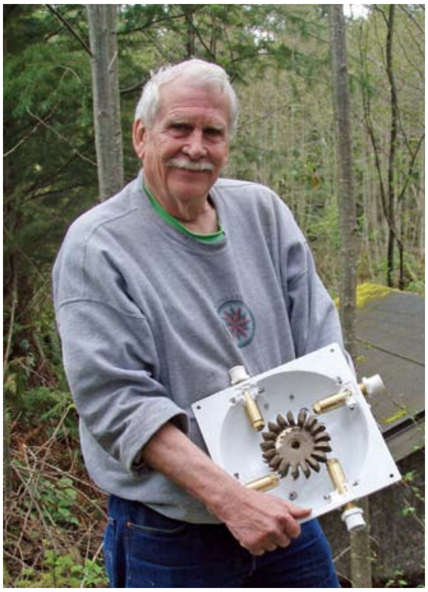
Obviously, water that is not moving has no energy in it. And water that is being pumped is not a source of renewable energy, since it takes more energy to develop the pressure than can be gotten back from it. Some fish-bearing streams may not be a wise choice for development due to environmental impact. And of course, you need to have legal access to the water source, and the ability to tap it without undue restrictions.

Very high-head sites (above 500 feet) can be costly to tap because of long pipe runs and high pressure. Tapping a part of the available head can be a viable solution. Also note that water sources that have very high water at some time in the year make for difficult intakes. High water often means a lot of debris comes down the stream, which can clog or damage intakes. And some intake designs do not function well if submerged.

Other inappropriate sources would be using drinking or irrigation water systems just to make electricity. These sources often rely on energy to pump and pressurize the water, so they are not actually renewable energy sources. And the intended end uses often need pressure, which a hydro system brings to zero. In addition, the volume of flow is usually not adequate to make much energy.

Courtesy Asian Phoenix Resources

Asian Phoenix's Power Pal low-head turbine in Honduras. At lower heads than this, things get tricky.



Courtesy Ian Woofenden

Hydro guru Don Harris

Q: Once you've identified a potential site, what measurements do you take to assess the site's production capacity?

What are the best methods for taking these measurements?

Several measurements are needed, and there are multiple ways to obtain most of them. Most important is to take very accurate measurements of head and flow. This will tell you how much power is available, and the type of turbine appropriate to the site.

To measure **vertical drop (head),** you can use:

- Altimeters, if meter accuracy is good
- GPS units (some may have enough accuracy)
- Survey level or laser level
- Maps with good contour lines, for higher-head sites
- Google Earth (in some cases) for offsite pre-assessment
- Accurate pressure gauge (if there is an existing pipeline)

An altimeter is used to survey elevation. This measurement shows only 180 feet of head, but with a 12-inch pipe, this site will develop 75 kW.

Courtesy SunWater Power Systems

The “bucket method” can be used to measure flow in small streams. Larger streams require an alternative measurement method.

To measure **flow** (this is best done multiple times throughout the year to ascertain seasonal variations):

- Bucket and stop watch to measure gallons per minute for small- to medium-flow sources and time surface velocity
- Weir with measuring notch and appropriate flow tables
- 100-foot (or longer) tape measure to determine the cross-section of stream

See “Intro to Hydropower, Part 2: Measuring Head & Flow” in *HP104* for more details.

Q: What do you consider to be the maximum feasible distances for penstock length and transmission wire run?

This depends on the scale of the system, the power available, cost of alternatives, the system voltage, and the terrain, among other factors. Penstock and transmission cable lengths of more than a mile are workable in the right situations, though less than 1/2 mile is more typical.

If you need long pipe and long cable, the site will need to be very good or the economics may not work. But if you need a long pipe and a short cable or a short pipe and a long cable, you may have a viable site. There are too many variables involved to generalize on distance limits, because so much depends upon the diameter and the material composition of the penstock that is required for the local conditions, and the voltage, distance, and size of wire.

Financial feasibility is usually the governing factor. How much is the power worth? Note that transmitting small amounts of energy, such as an energy-efficient household would use, can be pretty inexpensive over long distances. Every site is unique, and careful balancing of factors is required. Ultimately, the maximum feasible distance is directly related to the depth of your checkbook and what is “worth it” to you.

Q: What are the advantages of a microhydro system compared to other renewable electricity systems (wind turbine, PV array)?

A microhydro system will generate continuously, if it has a constant water supply. This alone is a significant advantage over either wind or solar power because a battery bank may not be required, and a smaller battery bank will suffice if one is needed. Also, microhydro is generally less expensive per kilowatt-hour than either wind or solar electricity. It’s working all day, every day. If you had a site where all three systems had equal potential near to the point of use, microhydro would probably be the least expensive choice per delivered watt-hour.

The hydrological cycle follows the human consumption cycle very well where summer cooling is not used. In winter, when a stream usually has more flow, households tend to use more energy; in summer, households use less energy and generally have less water. Solar electricity provides the opposite result, giving the highest yield in the summer, when you typically need less. Hydropower is there when you need it. When the sun goes down and the wind stops blowing, your hydro turbine will continue generating electricity.

95 psi shows the static head of almost 220 feet of head.

Courtesy EcoInnovation (2)

Q: What are the limitations of hydro-electric systems compared to other RE systems?

The main limitations of hydro-electric systems are the limitations of the water supply. No water equals no power. Few people have access to a good microhydro site—there are far fewer potential sites than solar and wind sites. And few people who live near good sites are aware of the potential of microhydro. Hydro is for one home in 1,000 at best, so the technology has only a light dusting of installations. These will generally be in rural environments near or in the mountains.

Even though hydropower is comparatively inexpensive and consistent, it requires special conditions that may be hard to come by. First, you need head, which usually means a location close to mountains. Second, it takes the land area to collect the water and develop the head. Third, it requires physical spaces for an intake, penstock, and power house. Fourth, the permitting process can be difficult, because you will be physically altering the watershed, even if only a little.

Courtesy Hydroscreen

The right intake design will affect system performance greatly.

Q: How do you assess the financial viability of a system, compared to, say, energy produced by a PV system?

A little simple math will answer this question. First, measure your head and flow and apply a formula to determine how much you can generate. Then get price quotes for the intake, penstock, and powerhouse equipment. Add it all up and divide by the lifetime energy you expect to produce, and you will have your cost per kilowatt-hour.

While every site has so many unique elements that generalizing is pretty risky, with an appropriate water supply, a microhydro system is usually many times less expensive than a PV system. Maintaining a microhydro system also can be quite inexpensive. There is just the one moving part, and bearing replacement is required only every few years. The intake can be the only point of regular maintenance, and the system shouldn't cost anything but labor to maintain. On the other hand, PV arrays that are mounted on fixed racks have no moving parts, or intakes, to maintain.

PV and microhydro systems aren't always treated equally with various incentives (rebates, tax credits, and net metering may only be available for PV systems), so that may also be a consideration. Financial viability is ultimately a personal assessment of the value of the energy produced for the system owner.

Q: What financial incentives are available for those who install a microhydro system?

Microhydro systems seem to have the fewest incentive programs worldwide. The incentives vary widely, so a generalization is impossible. If you have a farm, you may qualify for financial incentives to use the same water for multiple purposes.

Incentive programs tend to come and go, and can be fairly arbitrary. If you are counting on government money, act on it sooner than later. The paperwork burden in some cases can be significant. Check out your local incentive situation as part of the site assessment process.

Long-term, low-interest financing is quite a powerful incentive. Microhydro rebates tend to not be generous enough to affect the payback time very much, and therefore often don't

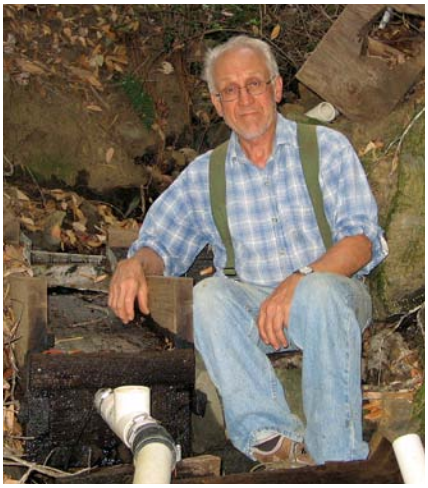
Hugh Piggott, Scoraig Wind Electric

Courtesy Scoraig Wind Electric

David Seymore, Asian Phoenix Resources

Courtesy Asian Phoenix Resources

Denis Ledbetter, Lo Power Engineering



Courtesy Lo Power Technologies

Courtesy Ian Woofenden

Christopher Freitas, WiFu Energy

Courtesy Hartvigsen-Hydro

Joseph Hartvigsen, Hartvigsen-Hydro

Courtesy Friends of Renewable Energy BC

Scott Davis, Friends of Renewable Energy BC

work very well. Every incentive situation is unique as well. Off-grid electricity from fuel-fired generators may cost something like $1 per kilowatt-hour to produce. This is a powerful incentive because well-designed and implemented off-grid microhydro typically costs less over the long term. Generators are noisy, stinky, and expensive. By contrast, a microhydro system can quietly run for years on end, dependably providing energy with a minimum of hassle and no emissions.

Q: In what cases do you advise people to go with an alternative to microhydro?

The decision on which resource to use for an RE system depends on:

- Economic issues: what do they pay for electricity currently? How have rates increased over the years, and what's their expected rate of increase?
- Location
- Grid availability and connection costs
- Quality of the hydro resource
- Household energy consumption
- Homeowners' environmental philosophy

Q: What is the typical process required to get regulatory approval for home hydro systems, and where do potential users find information about it?

Local regulations vary widely. Water rights are regulated everywhere and must be respected. Wherever you are, check with appropriate authorities before spending significant money on construction. Start with the water resources department where you live. Some states have little to no requirements and some states have a great deal of red tape.

It should be about natural law and ecology with good sense, and most small hydro systems have a very minimal impact on the environment. From anecdotal reports, many home-sized systems are not permitted because the level of regulation is out of scale with the potential impact, and the value of the systems to small landowners exceeds their desire to work with bureaucracies. For larger grid-connected systems, it can run the gamut—from just getting local water regulator permits to having to appeal to the Federal Energy Regulatory Commission for licensing or exemption. Both levels seem to be arbitrary and indeterminate processes. Working the system seems to be much more practical abroad, such as in the U.K.

Q: What are common challenges encountered in installation?

Each site has its own challenges, but most are overcome by the use of common sense and some basic engineering skills. Steep, wooded terrain and rocky stream courses can make installation more difficult.

Specific challenges include:

- Intake site selection and installation
- Proper pipe selection and installation, including dealing with poor access and long distances
- Routing pipeline or power line over rough or steep terrain
- Avoiding private land, public land, or road crossings
- Air blockage in pipes laid with an uphill slant
- Proper transmission cable selection, installation, and protection
- Inaccurate measurements of head, flow, and distances
- Protection of penstock from sun, slides, and other physical damage
- Permitting and regulatory issues
- Freezing conditions (i.e., ice plugging screens and low water levels)

Another significant challenge in microhydro installation is finding local, experienced installers. Many more people install solar-electric systems and some also install wind-electric systems with some level of expertise, but microhydro is the most obscure of the renewable technologies.

Courtesy SunWater Power Systems

An excavator lifting a 3,000-pound section of 8-inch steel onto a steep slope. The pipe was then pulled 500 feet up the hill using the excavator and a long steel cable through a pulley.

Q: Have there been any notable advances in turbine, control, or system design strategies in recent years?

There have been only a few major advances. Some improvements have been made by tweaking original designs, such as adjustable guide vanes on certain low-head, propeller turbines and adjustable permanent-magnet alternators.

Modern electronic load controllers have freed us from the need for the elaborate and delicate mechanical speed-governing systems used in the past. Inexpensive permanent magnets now allow manufacturers to offer very efficient, simple battery-charging alternators. The use of induction motors as generators has reduced the cost of basic AC hydro systems.

Hydropower systems continue to become more efficient and reliable, but most hydro systems are based on fundamental principles that have been proven for more than 100 years. New on the scene is the ability to maximum power point track (MPPT) a hydro turbine, which can solve some of the mid-range transmission issues mostly for 12- or 24-volt systems. MPPT controllers allow a hydro turbine to run above battery voltage, allowing longer wire runs and more efficient output—both in the operation of the turbine and in the line losses. And rather than having to manually adjust some alternators' magnetic field as battery voltage and flows fluctuate, a MPPT controller can do it electronically.

Grid-tied equipment is gradually moving into the microhydro world, increasing the opportunities to sell energy to local utilities. "Bleeding edge" technology has experimenters using PV arrays as part of hydro control strategies (using the array as a zener diode) in both battery-based and batteryless systems.

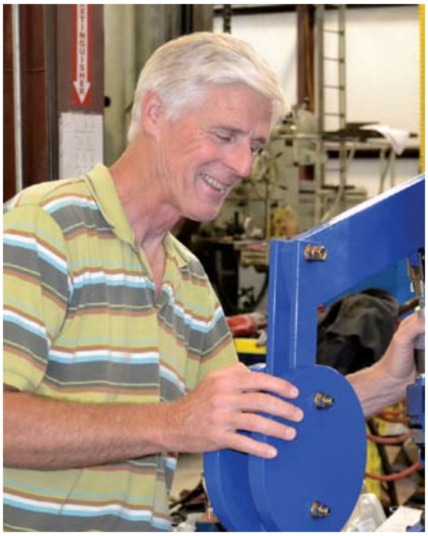
Q: What kinds of maintenance do microhydro systems require?

As with all machines, hydropower systems require maintenance. Bearings must be checked occasionally and lubricated as necessary. Intake systems must be cleared of debris that might hinder water flow. When there are seasonal changes in flow, it may be necessary to change nozzle or gate settings. In some cases, ice at intakes can be a problem. You may need to check that the pipeline is free of damage and supporting anchors are secure. Other maintenance includes replacing generator bearings and periodically checking electrical connections for corrosion.

It's good practice to shut down your hydro system at least once a year to inspect the runner and other hydraulic components for wear. For battery-based systems, you need to care for your batteries, ensuring that they are sized correctly to start with, and that they are fully charged most of the time to get the best life from them. Top up with distilled water when needed.

Properly maintained, a quality hydro system will run reliably for many years.

Mike New, Canyon Hydro



Courtesy Canyon Hydro

Michael Lawley, EcoInnovation

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Robert Weir, Hydroscreen

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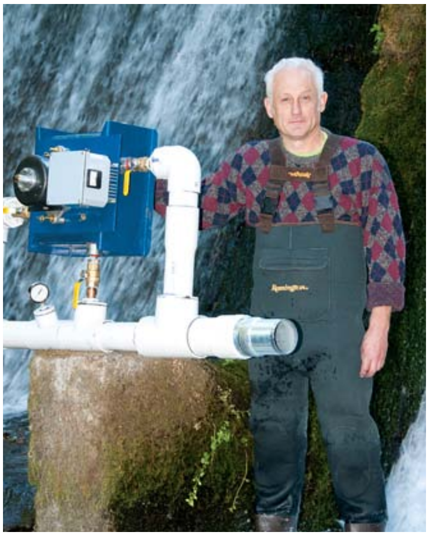
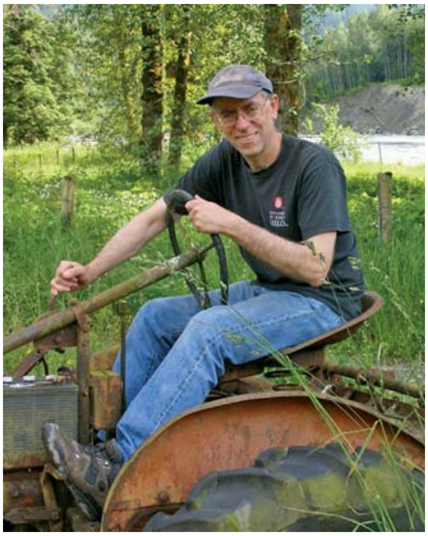
Derik Veenhuis, Hydro Induction Power



Shawn Schreiner

Jerry Ostermeier, Alternative Power and Machine



Courtesy SunWater Power Systems

Peter Talbot, SunWater Power Systems

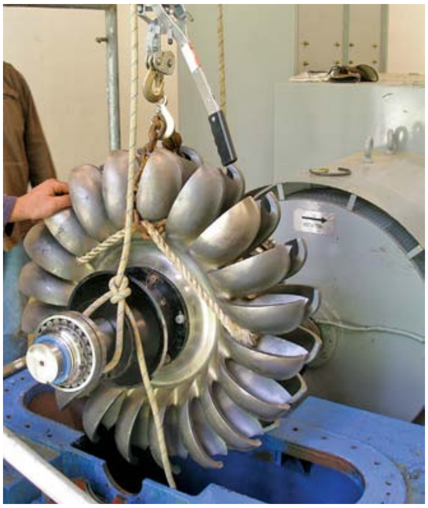
Access

Michael Lawley, director and engineer at EcoInnovation in New Plymouth, New Zealand, has a degree in mechanical engineering and has lived off-grid for the last 16 years. EcoInnovation manufactures hydro turbines using renewable energy. www.powerspout.com

David Seymour, president and CEO of Asian Phoenix Resources in Victoria, BC, Canada, is a semi-retired mineral exploration geologist who, while working in Vietnam, recognized the positive impact that individual low-head microhydro turbines had on the residents of remote settlements. For 14 years, he has been supplying PowerPal microhydro products to more than 80 countries. www.powerpal.com

Hugh Piggott, owner of Scoraig Wind Electric in Scoraig, Scotland, lives off-grid in windy northwest Scotland and specializes in homebuilt wind turbines. He would specialize in hydro if he lived in a suitable location, and has installed a number of small off-grid hydro systems ranging from 20 to 7,000 watts. www.scoraigwind.com

Jerry Ostermeier, owner/engineer at Alternative Power & Machine in Grants Pass, Oregon, has been focusing on hydro and off-grid applications in the renewable energy business for 32 years. www.apmhydro.com



Courtesy SunWater Power Systems

This heavy runner is being inspected for wear and bearing replacement.

Mike New, vice president of Canyon Hydro in Deming, Washington, is a longtime hydro enthusiast who wrote the *Guide to Hydropower* and developed the public information site www.whyhydropower.com. www.canyonhydro.com

Christopher Freitas, an electrical engineer with WiFu Energy in Big Lake, Washington, is a hydro system owner and renewable energy engineer who has worked in the RE industry since 1986. Recently, he's focused on projects in the developing world, including Haiti, South Sudan, and Pakistan. www.sunepi.org

Peter Talbot, owner of SunWater Power Systems in British Columbia, Canada, made his first hydro generator at age 8, and still enjoys the simple concept of harnessing flowing water to do useful work. To him, it's not a job; it's a passion. www.homepower.ca

Scott Davis, president of Friends of Renewable Energy BC in Victoria, BC, Canada, is a renewable energy project developer and the author of *Serious Microhydro: Water Power Solutions from the Experts* and *Microhydro: Clean Power from Water.*

Joseph Hartvigsen, owner of Hartvigsen-Hydro in Kaysville, Utah, has been building water turbines for a dozen years. While hydropower has always been a fascination, his direct involvement arose out of necessity to provide power on the family's mountainous wheat farm in Idaho. www.h-hydro.com

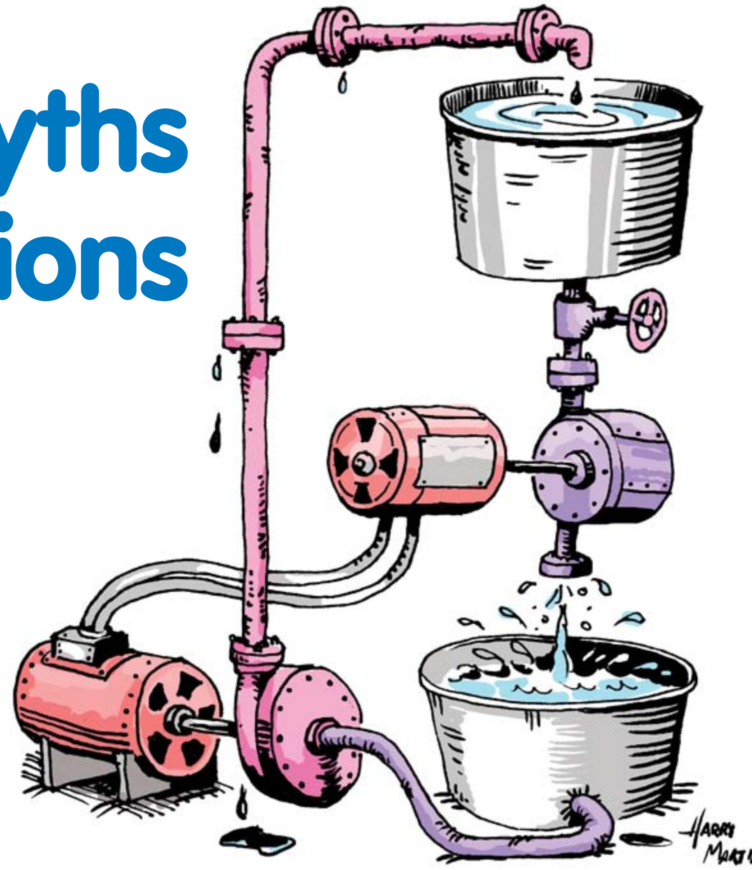
Denis Ledbetter, owner of Lo Power Engineering/Harris Hydro in Redway, California, divides his time between his family's homestead in the coastal mountains of northern California and using RE to manufacture the Harris microhydro turbine.

Robert K. Weir, president of Hydroscreen in Denver, Colorado, is a registered professional engineer with 43 years experience in diversion and screen engineering. He works directly with owners and engineers to design functional, cost-effective screening applications. www.hydroscreen.com

Derik Veenhuis, owner of Hydro Induction Power in Redway, California, has been working in renewable energy and building hydro turbines since 1980, developing his own line of low- and high-voltage turbines. www.hipowerhydro.com

Microhydro Myths & Misconceptions

by Benjamin Root



Making electricity from falling water can seem like magic, and that's led to lots of misconceptions. Here, we'll separate fact from fiction when it comes to what microhydro systems can and cannot do.

Residential-scale microhydro-electric systems have the reputation of being the holy grail of home renewable-energy (RE) systems. While they lack some of the hype, magic, and bling of solar-electric (photovoltaic) systems, microhydro systems are a simple technology that most people can understand…at least in general. In this article, we'll look at some common microhydro system *misconceptions*, most of which come from folks looking for shortcuts to the reward of cheap electricity.

Modern microhydro equipment comes from proven technology based on designs that have changed very little over the decades. Pelton and turgo wheels, the typical spinning water-wheel component, were invented in 1870 and 1919, respectively. The point is, this technology has proven its reliability and functionality with more than a century of performance.

The cost of these systems, and thus the cost of the resulting electricity, also has the reputation for being very reasonable when compared to other renewable or home-generated sources. While PV module prices have recently dropped, they are still a high-tech and expensive commodity. Microhydro systems can arguably be considered *low-tech*, with civil works and pipelines often being the majority of the system cost. Of course, the actual cost varies significantly from site to site, and from system to system.

Another element that keeps microhydro-generated electricity low in cost, and thus high in desirability, is the system's continuous duty cycle. While PV systems only produce electricity when the sun is shining (and wind-electric systems when the wind is blowing), microhydro systems aren't affected by nightfall or weather blocking the sun. Even a small hydro resource can provide electricity 24 hours a day, and often 365 days a year (if the water source is year-round). The bottom line for any renewable energy system is the amount of energy it can produce annually. A low power source working all of the time can often produce a lot more energy than a more powerful source that only works intermittently.

So, why doesn't everyone have a microhydro system? Herein lies the challenge. A viable hydro resource is dependent on the availability of falling water at, or near, the site of the electrical loads. It is the weight or pressure of that flowing water that spins the turbine to produce electrical energy. Not everyone has access to a stream or spring of adequate volume on their property, nor does everyone have the topography to create the vertical drop needed to pressurize that water with gravity. See the "Microhydro Rules" sidebar for a formula about how water flow and vertical pressure (head) combine to determine the power available from a potential hydro site. That site-assessment formula will help debunk some of the myths that follow.

Many microhydro misconceptions are a combination of misunderstanding some of the basic properties of physics, and an overzealous optimism about the potential of RE resources. Here, we hope to correct the misconceptions about physics, while at the same time further encouraging educated optimism. Once you've had a little reality check here, we suggest you read some of *Home Power's* other articles on the basics of hydro site assessment and microhydro systems (see Access at the end of this article). Perhaps you really do have untapped hydro potential waiting for you.

web extra

For more on microhydro systems, see "The Basics" at **www.homepower.com**

Myth 1: Closed-Loop / Pumped Storage

By far, the most common flawed design that we hear about at *Home Power* is the closed-loop system—that is, some scheme to pump water for the hydro turbine, and then have the turbine produce the electrical power for the pump…ad infinitum. Some of these schemes are simple "hydro-in-a-bucket" designs where the pump is expected to pressurize the water for the hydro turbine. Others are more involved, planning to pump water uphill to a pond or tank, and then let gravity do the job of running the turbine. All the while, the designer is expecting to get *extra* usable electric power from the turbine's output—beyond what the pump is using. Whether large or small, all of these designs suffer from the same flaw in thinking.

The first law of thermodynamics says that energy can neither be created nor destroyed. All of the energy systems (renewable and otherwise) that we rely upon *convert* existing energy into a form that we can use to do the work we want to do. In a hydro-electric system, the energy of moving water is transferred to a rotating shaft, converted to changing magnetic fields, and then converted to moving electrons (electricity). But at no point is energy *created.* If we use that energy to create magnetic fields again, spinning a shaft and pumping water up to a tank on a hill, we still haven't created any energy. We've just changed its form again.

In a perfect universe, perhaps it could be argued that such a pump and turbine arrangement could run *perpetually*. But it wouldn't do us any good, because we want to use that electricity to do some work besides just running the pump. Using any electricity for other tasks would be robbing the pump of the power it needed to keep up with the turbine, and the loop's interdependence would break down. That, and the fact that there are always other forces robbing energy from the system, means that such a loop wouldn't run for long, and that *no* additional energy could be extracted from it.

Those additional energy-robbing forces, mostly friction, are the imperfections that cripple this closed-loop design. Every component of such a system has an operating efficiency of less than 100%. That means each conversion step in the process wastes some of the potential energy that the system started with. We know that energy is not being destroyed, but it is being allowed to escape the loop in the form of heat, vibration, and even noise. It is being converted into a form that we can't readily use, or even recover.

Let's look at some typical microhydro system efficiency numbers:

- Penstock (pipeline) efficiency = 95%
- Nozzle and runner efficiency = 80%
- Permanent-magnet alternator efficiency = 90%
- Wiring and control efficiency = 98%

0.95 × 0.80 × 0.90 × 0.98 = 0.67

By the time the water has moved through this example microhydro generator system, only 67% of its initial potential

Microhydro Rules

The instantaneous power available from a microhydro system is based on two main factors:

- The quantity of water (per unit time) moving in a river or stream, and that is available to be diverted through the turbine, is called *flow*. It is expressed as a rate such as cubic feet per second (cfs) or gallons per minute (gpm).
- The pressure that drives that flow is caused by the vertical height between the intake and the turbine. The *head* is basically the weight of that water column and can be expressed as pressure (psi or bar), but is more often discussed in terms of vertical *feet* of head since that relates directly to the topography of the site—2.3 vertical feet of water will create 1 psi.

Together, head and flow are the driving forces that spin the turbine at the bottom of the system. A hydro system designer will use these two measurements to determine the pieces and parts necessary to optimize a system. Intake and turbine locations will be chosen to maximize head, while minimizing pipe and wire runs and other site-specific challenges. Pipe will be sized to balance reducing friction loss with keeping costs in check. The number of nozzles, runner type and size, and alternator size will all be carefully balanced to work with available flows without depleting the source (and ideally, without negatively impacting the local ecology). And the efficiencies (inefficiencies) of each component in the process will be calculated for an accurate estimate of the power available at the site.

But there is a simple formula to guesstimate a site's general hydro potential without going though all of the formulas and variables of turbine choice and pipe sizing:

Head (vertical ft.) × Flow (gpm) ÷ Derate factor = Power (W)

The derate factor is commonly between 9 and 13. This range has been determined over the years from the measured real-world performance of professionally installed hydro systems. A low derate factor like 9 would be appropriate for cases with good head and flow, and relatively short pipe runs and other inefficiencies. Higher derates, like 13, would be for cases where either head or flow (or both) is challengingly low, or other obvious inefficiencies will occur. This factor also takes into account the canceling out of units to arrive at watts; do not try this formula using cfs, psi, or other units of measurement.

In some of the myths in this article, this formula is used to illustrate example scenarios. Because these myths are so fallacious, we can use a nice optimistic 10 as a derate factor. (In fact, with the tiny systems described, the derate might actually be twice that.) Besides making the math easy, you'll find that even giving a myth this benefit of the doubt won't make it stand up to the real tests of physics, financial viability, or both.

You should feel encouraged to use this formula as a starting point in assessing your site's hydro potential. It may help you decide if you should contact a professional system designer, or drop the idea. Besides, the variables you used in the formula will be the first questions that a pro will ask, (so make them accurate). Knowing your site's *measured* head and flow in advance will save everyone time and money. (See "Intro to Hydropower Part 2: Measuring Head & Flow" in *HP104*.)

energy has been converted to electricity. In fact, this would be considered very good performance—typical systems are about 55% efficient.

Now let's consider the efficiencies of pumping that water back to the hydro intake for reuse:

- Pipe efficiency = 95%
- Pump (motor and impeller) efficiency = 65%

0.95 × 0.65 × 0.67 (from above) = 0.41

By the time the water had gone all the way through the system, only 41% of it would be returned to the top of the intake. After a second loop around, only 17% (0.41 × 0.41) of the water would be left.

If there isn't a water supply with useful head and flow to start with, *nothing* will happen—the pump won't run because it won't have electricity; the hydro turbine won't have electricity because the pump isn't running. Adding water (or electricity) to "prime" the loop will make the loop operate only as long as the priming continues.

This is where creative folks start asking questions about bigger water tanks; larger pipes with less friction loss; tanks on a tower for shorter pipe runs; more head, and less flow; less head and more flow; adding batteries (only 80% efficient themselves); or even just piping right from the pump to the turbine—anything to improve system efficiency. In fact, the simplest thing that could be done to get rid of inefficiencies would be to skip the water components altogether; just hook the shaft of a motor directly to the shaft of the alternator, and the alternators output wires directly to the motor (somehow, the fallacy in that thinking is easier for us to understand). But no matter the variables, the outcome will be the same—total efficiency will be less than 100% and no energy will be gained.

Moving energy around and changing its form, like from chemical to mechanical to electrical, is only a way to lose some of it. These efficiency losses are part of the price we pay to get energy into a format that we *can* use. We can lose more, or we can lose less, but adding complexity is inefficiency and will never result in a net gain.

Utility-Scale Pumped Storage

Utility-scale hydropower facilities *do* pump water uphill. But their goal is not so much to gain or create more energy as it is to reduce overall losses. The utility grid needs to be able to provide power on demand, but its power plants (coal, natural gas, nuclear, and hydro) are slow to come online or take offline. And solar and wind facilities sometimes make power when it's not needed. To meet changing customer needs, plants are often running "in wait," with nowhere to send that power—that energy is potentially wasted. Hydro facilities can divert that unused power to pumping water back to the top of the hydro dam, where the potential energy can be stored for use when loads on the utility grid surge again. The reservoir is used like a giant battery for grid energy. And while efficiencies on that pumping are 70% to 85% (a 15% to 30% net loss), that's a lot better than wasting *all* of the excess power of idling power plants.

Myth 2: Rooftop / Downspout Hydro

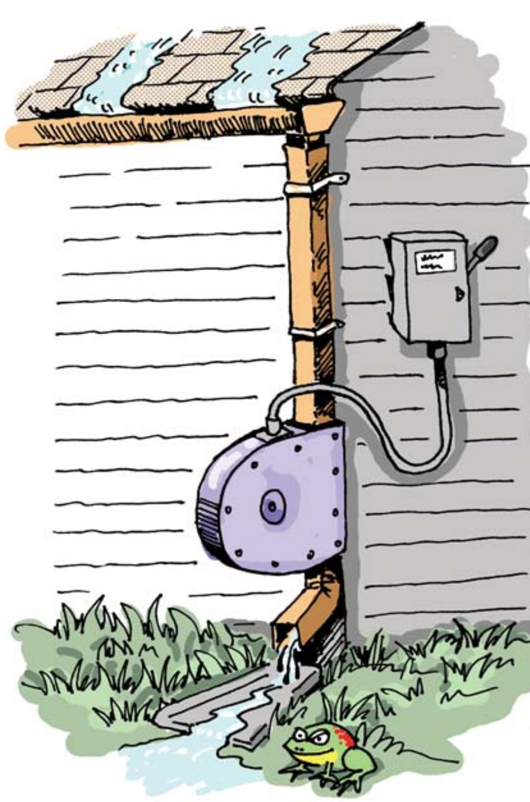
A second common microhydro-electric scheme that we are often asked about is the viability of putting turbines on a home's gutter downspouts to generate electricity from the rain. Some imaginative folks know enough about hydro to understand that the energy has to come from somewhere (in this case, from the forces of nature), and that the height of the roof can contribute head (pressure) to spin that turbine.

The mistake in this scenario is a simple and honest one of scale. While some hydro units have been designed that can function on low head, such as from the roofline of typical homes (and even lower), a hydro turbine's power output is a product of head *times* flow. And it is a lack of significant flow that is the defeating factor in the power equation when relying on rooftop rainwater collection. The watershed drainages for even small streams are usually measured in thousands of acres or square miles. Home roofs, even big ones, are measured in mere thousands of square feet.

Let's look at example calculations for a large house in a very rainy place—Seattle, Washington, gets about 40 inches of rain per year, with November being the rainiest month at an average of about 6 inches.

Let's assume that a tall two-story house would give us a 25-foot-high roof, and thus 25 feet of head. This 6,000-square-foot home has about 3,000 square feet of rainwater collection area (remember, it's two stories). That means that in November, this house would receive about 1,500 cubic feet of rain, or 11,220 gallons.

If that rainfall came as a constant drizzle all month long, flow from the roof would be only about 1/4 gallon per minute. Currently there is no turbine on the market to



work with that flows that low, but using our microhydro power formula (see sidebar), we could theoretically get 468 watt-hours that month.

0.26 gpm × 25 feet ÷ 10 derate = 0.65 watts × 720 hrs./mo. = 468 Wh

So even if there was a nanohydro plant that could harvest that small flow, it would result in less than 1/2 kWh of electricity—per month!—and only 3 cents worth of electricity in Seattle. It's a tiny fraction of what even an energy-efficient, 6,000-square-foot home would use in a day, not to mention a whole month.

Would the available energy increase if we weren't dealing with a constant drizzle? What if, to increase flows to a usable rate, and hopefully increase viable energy production, we could hope that all that rain came in a great deluge of 1 inch per hour (a 100-year storm, in Seattle) over six hours! At that unlikely amount of rain—practically all at once—flow from our example roof would be about 31 gpm. That is a more viable flow rate for hydro turbines on the market and gives us a projected power production of 77.5 watts, but only for those six hours. The total of 465 Wh per month is about the same energy as the drizzly example above (the minor difference is from rounding significant digits).

This is when inventive thinkers will begin planning for taller homes, or additional rain-collecting roof areas, and tanks to hold the water for release all at once to increase flow. But even that 11,220 gallons of water that falls on our 3,000-square-foot roof that month would weigh almost 47 tons if stored. Imagine a structure at roof level capable of supporting that kind of load just to generate a minuscule amount of energy. And remember, these discouraging energy production numbers are for the rainiest month, in one of America's rainiest cities. Other months, other places, and smaller houses can only deliver worse performance.

In this case, it would be better to just spend the money on a PV system. To put things into perspective, even in Seattle, which gets only an average of 1.7 peak sun-hours per day in November, an inexpensive (less than $100) 15-watt PV module would make close to the same amount of energy as the proposed rooftop hydro system.

Myth 3: Hydro from Municipal Water Supply

So, a thinking person might begin wondering where they could get good water pressure and adequate flow necessary to run a microhydro turbine. It's the kind of question an inspired hydro wannabe might ponder, say, while standing in the shower. And that's when another common hydro scheme is hatched.

Typical municipal water pressure is between 40 and 80 psi, the equivalent of 92 to 185 feet of head. That is definitely enough for a hydro system. And if available flow is about 10 gallons per minute, say at the bathtub faucet, then surely there must be some real power available whenever we turn on our faucets.

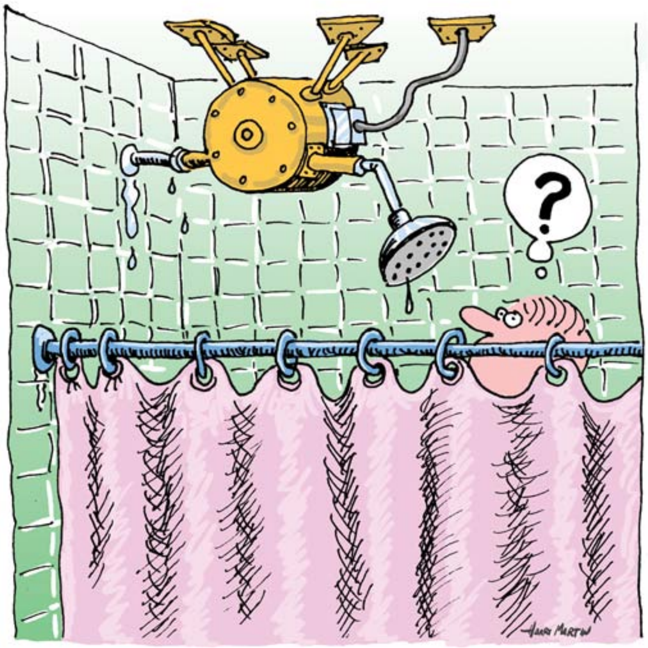
However, if we use our example power formula with a common pressure of 60 psi (138 feet), we get a projected power output of about 138 watts.

138 ft. × 10 gpm ÷ 10 derate = 138 W × 24 hrs. = 3,312 Wh per day

That 3.3 kWh per day is something—but not a lot. An *average* American household uses about 30 kWh per day, so would need nine of these units.

For the sake of argument, let's assume a very energy-efficient home that could run on 3.3 kWh per day. Why not then use such a hydro system? Or, why not offset a portion of a home's loads with hydro? Every little bit helps, right?

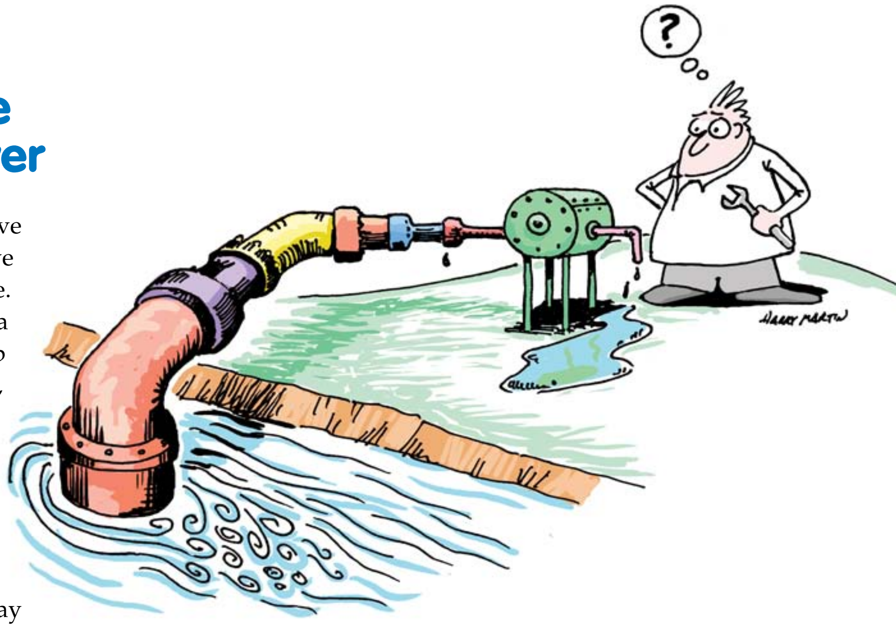
The 3.3 kWh figure is based on using 10 gallons per minute—*24 hours per day*. That's 14,400 gallons per day. At an average cost in the United States of $1.50 per 1,000 gallons, that's $21.60 per day in water costs just to generate 36 cents worth of electricity (based on the U.S. average of $0.11 per kWh).



Then there is the ecological and moral impact—remember, this is water that has been treated and purified for human consumption, and uses pumps to maintain that pressure—processes likely paid for in part with taxpayer money. Costs aside, what are the implications of pouring good clean water down the drain just to make a little electricity?

Finally, just to add a final coup de grâce to this hydro scheme, remember that most of what we do with our domestic water requires water pressure, as well as flow, to get the job done. Taking the energy out of water to make electricity robs that water of its pressure—water merely falls dead (depleted of energy) out the bottom of a hydro turbine. And pressure at other faucets may be anemic at best—imagine trying to rinse shampoo out of your hair while a hydro system is running full-bore in the same home. Not so effective, or enjoyable.

Myth 4: Reducing Pipe Size to Increase Pressure / Power



There is no substitution for head and flow in an effective microhydro system. When head is inadequate, we begin to think of creative ways to increase pressure. The simple example of watering the garden with a hose comes to mind. Doesn't putting your thumb partially over the hose opening increase the pressure, shooting water farther across the lawn? What if you use a spray nozzle instead of your thumb? Didn't you just increase the power of that system by reducing the size of the nozzle? And therefore, couldn't you increase head (and thus power) in a hydro system by starting off with a large pipe diameter and then reducing the pipe size on the way to the turbine?

Sorry, but no. When a pro measures head in a hydro system, they note two different types. Static head is the pressure at the turbine with the bottom valve closed, and thus no water moving. It is the pressure, from the weight of all the water in the pipe above the turbine. This pressure, measured in pounds per square inch (psi), is in direct proportion to the height of that column of water. For every 2.3 feet of vertical head, you'll measure 1 psi. Because it is directly proportional, there's no need to put in pipes and fill them with water to measure it; just measuring the vertical drop between water source and turbine site will give you an accurate static head.

But static head is just a maximum starting point. Dynamic head is the adjusted theoretical pressure in the system when inefficiencies like friction loss of pipes, joints, elbows, and valves are considered. These things hinder the flow of water through the system, and therefore some of its potential energy. Dynamic head is the result of static head minus these power losses, and provides a more accurate estimate of turbine performance.

Adding a smaller pipe section or nozzle is basically adding another restriction in the pipe that creates resistance to the flow of water. It effectively lowers the dynamic head of the system and thus also lowers the total power available in the system.

"Wait," you say, "what about the hose spraying farther across the yard?" Or maybe you are savvy enough about hydro systems to know that impulse turbines actually use nozzles to shoot a stream of water at the spinning runner. Well, you are right, but neither pressure nor power are being *increased* by the nozzle. Instead, the existing energy is being concentrated into a smaller point and at higher velocity—which is a more usable form for the turbine—but, in the process, some of that energy is lost to friction.

The purpose of a nozzle is to increase the kinetic energy of the flowing water by increasing its velocity. But this is at the expense of its potential energy in the form of pressure. In fact, on the outlet side of a nozzle, there is no pressure in the water; it is carrying all of its energy in the form of fast-moving kinetic energy. And it is the force of this kinetic energy against the turbine's runner that makes it spin. But no increase in energy was created. In fact, that water moving faster through a nozzle has more friction loss, reducing our dynamic head and total available power in the system—less power, but in a more useful form.

There is never any more power available than the theoretical maximum based on the initial static head (at a given flow). Every component and change in the form of energy in the system acts as an inefficiency, reducing actual available power. Some of those losses are necessary ones (getting the water down the hill, shooting it at the runner, etc.). Good design can reduce losses, but they can never be eliminated completely. And they definitely can't be changed to net gains.

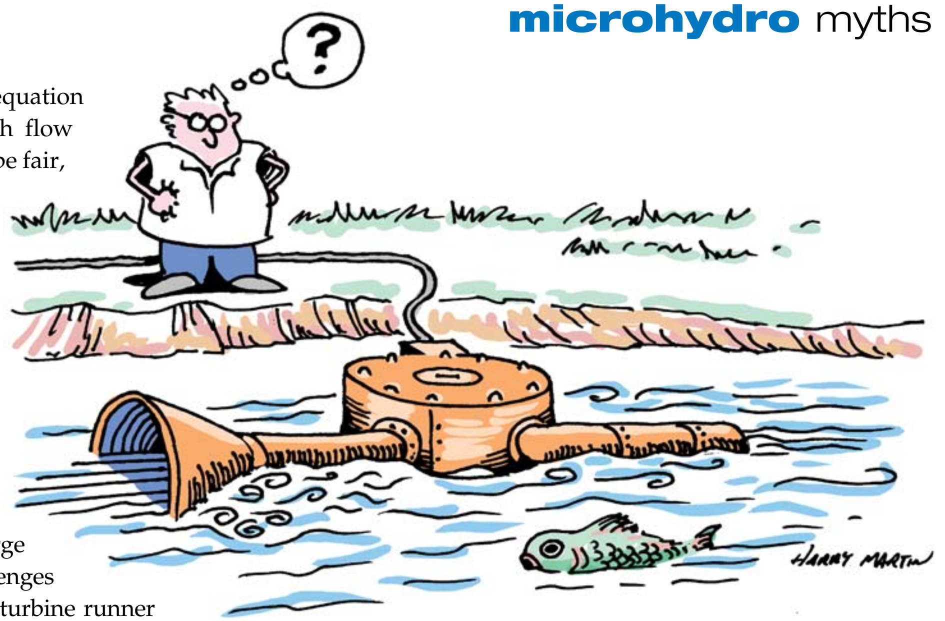
Myth 5: In-Flow / No-Head Systems

It's starting to sound like only those folks with a stream or river on their property have a viable hydro system. But if you do have a good-flowing stream, you're all set for hydro power, right? Well, it's even more complicated than that.

We know that the power available to typical hydro turbines is a product of the head (pressure) and flow rate. So we also know that as head decreases, flow must increase to make the same amount of power. But what about folks with a nice river flowing along relatively flat ground? There must be some energy available in that strongly moving mass of water, even though it isn't falling from a height, right? Well, yes and no.

Besides just turbine size, there are different turbine technologies designed to take advantage of the ratios of head-to-flow at a given hydro site. But as head decreases, the energy gets harder and harder to capture. Reaction turbines, designed for low heads (as low as 2 or 3 feet) spin inside a column of falling water, but need high flow for significant power.

But what about situations with basically no head at all? What about that big river flowing through a flat plain? Well,



try putting zero head into our hydro power equation and you will find that, no matter how much flow there is, the power output will be zero, too. To be fair, there must be some head for the water in a stream to be moving at all, and thus there must be some power there to capture. But even though the movement of that flat-water stream looks enticing, there isn't much potential to start with, compared to the same water dropping down a hillside. And then there's the challenge in capturing it.

To make up for lack of head, flow would need to be substantial. Either the river must be flowing very fast, and/or a very large area of river must be captured. Both create challenges in the integrity of the mounting structure and turbine runner itself, plus the added danger from river debris.

A fast-moving river is often only moving fast in the center. Near the banks, shallows, or along the bottom, friction reduces the flow. The speed of the river in the center can't necessarily be extrapolated to the whole cross-sectional area. Instead, there are specific formulas to account for the reduced flow along the bottom and shallow sides of a stream.

And even a quickly flowing river is moving a lot more slowly than the runner in a jet-driven impulse turbine in a system with higher head. A slowly spinning runner needs to be geared to create the rotational speeds necessary to generate electricity with an alternator. The gearing adds further complexity and friction loss to the system—more inefficiency.

We're not saying that it can't be done. But we are saying that it's unlikely that you can buy anything off the shelf that will do an adequate job for you. There have been, and will continue to be, many inventions intended to capture energy from the flow in a river. These "in-flow" or "current turbine" designs come and go, and come again, but we rarely see anything that performs to a level that warrants a reliable consumer product. There are a couple of in-flow products on the market (Ampair and Jackrabbit) that were originally designed for towing behind sailboats or barges. Some have adapted these to use in streams, but the small swept area of their propeller requires high-velocity flow to make much usable power.

If you are a tinkerer, and enjoy the creative challenge of hydro design, you may be able to fashion an in-flow turbine to make some power (though it may never pay back financially). But if you are being tempted by commercially available in-flow turbine designs, caveat emptor. Do your homework by talking to other reputable hydro installers about your resource and options. Be realistic about your capturable stream area and flow rate. And ask for real-number data, and references, from the turbine manufacturer.

Head & Flow: Check Your Reality

While microhydro power is a reliable and proven technology, often at a reasonable cost, it's completely dependent on the resources available on a site-by-site basis. Either your site has reasonable hydro potential, or it doesn't. And it all depends on the quantities of head and flow. There's no cheating the laws of physics. There is no way to *create* energy. There is no free lunch.

That doesn't mean that there aren't ways to optimize your hydro potential to get the most energy out of your resource. That's where professional designers and reputable manufacturers come in. They have the knowledge to make decisions on siting and equipment that will maximize the energy made from the head and flow that is available. Intake type, pipe sizing and routing, the size and number of nozzles, runner type, alternator size and type, controller type, and system voltage are all variables that, when combined properly, will make or break your system performance and financial viability.

So give up on the free energy designs. Instead, read some of *Home Power's* real-world articles on hydro system design, do a preliminary measurement of your stream's actual head and flow, and call a reputable microhydro professional. That's the best scheme for maximizing your hydro system's performance.

Access

Benjamin Root is no expert on microhydro power, but with 15 years on staff with *Home Power*, he has seen a frustrating repetition of misconceptions about renewable energy's potential…and hydro seems to take the brunt. Before you try to debunk Ben's debunking, he suggests you do the same thorough research that he did to write this article.

Related microhydro articles in *Home Power*: *HP103*, *104*, *105*, *117*, *124*, *125*, *126*, *132*, *136*

Electrify Your Ride

DIY

Converting Your Bike to Electric

Story & photos by Ted Dillard

I have to confess—bolting a motor onto my bike has been a fascination of mine since I was a kid and first saw the DIY gas bike kit ads in the back pages of *Popular Mechanics.* It was probably second only to the idea of strapping a bunch of hot-air balloons to a lawn chair and coasting over the trees in my neighborhood.

Although I've come close to building something like my motorized bicycle boyhood fantasy, it always got eclipsed by something more practical—until I saw the electric conversion kits.

Converting a standard bicycle to electric power is remarkably simple. You can approach it from a complete DIY perspective and build it all from scratch; you can adapt motors and parts from salvaged electric scooters; or you can buy complete turnkey kits with everything you need—instructions and all. Finally, the fantasy became practical.

The newly electrified bike goes for its first test drive—with success!

Why Go Electric?

There are plenty of reasons that people like electric-powered, or electric-assist bikes. They're so much simpler, smaller, and lighter than electric motor-scooters or motorcycles; they can be pedaled efficiently and easily; and, in most states, you don't need special licensing or permits to ride them. Electric scooters' pedals are just for regulatory show—to qualify them for "motorized bicycle" status in the eyes of the government. They are too heavy to pedal, realistically. Electric bikes allow an avid bicyclist to enjoy the open road, and help out on the hills or on that long road home. They can help you keep up with the group, if you like to ride with more extreme bicyclists.

They also let you pull more weight—for a trailer, groceries, or gear to the beach—and you can jump on the bike, run your errands, and come home without a huge workout. You can use the bike for a commute, and arrive ready for work without the need for a shower and a change of clothes.

Police departments find an advantage in electric bikes: They can pedal around all day, and enjoy all the benefits, tactical and otherwise, of "bike detail." However, if they get a call some distance away, the 30 mph top speed of many of these bikes can quickly get them where they need to be without being winded when they arrive.

For city dwellers, electric bikes are light enough to bring into a building and up elevators for storage and recharging in your apartment—something you just can't do with an electric motor-scooter. If you're keeping yours on the street, the removable batteries of an electric bike allow for easy in-apartment charging.

"Range anxiety" is avoided with an electric bike. If you run out of battery energy, you simply switch to leg-power and pedal your bike home or to the nearest electrical outlet.

Conversion Parts

Factory-built electric bikes can cost in the $1,200 to $1,800 range, not prohibitive to bicycle enthusiasts, but the kits can be cheaper, from $400 on up. The components include the bike, motor, motor controller, batteries, and rider controls. There are a few extras available, but those are the basics.

A rear-wheel hub motor.

Bikes. The choice of bike for the conversion process really is up to you. Kits are made to accommodate standard, modern designs. With the exception of only a few obscure models, nearly any bike will convert easily.

I bought a new bike specifically for my conversion, so there was a lot to choose from and no repairs or alterations were needed. Most electric bike shops are willing to talk about the process of electric conversion. East Coast Alpine, in Danvers, Massachusetts, helped us find a bike that would be a good fit. Many bike shops are beginning to add electric bikes to their product offerings, so it's something they're embracing.

An outboard-mount Currie motor and drive.

Motors. The most common type of bike conversion motor is the hub-integrated motor, built into the wheel—there's no drive train to deal with and no radical modification of the frame required. Generally, you buy the motor and wheel as a prebuilt unit. They are built to accommodate the drive gears of your pedal-bike, and its braking system. You simply place the order and specify what size and type of wheel you need, and the motor/wheel comes complete. Installing it is simply a matter of mounting the tube and tire on your new wheel, and replacing the original wheel with the powered one.

There are two basic types of integrated hub motors: geared, and direct drive. The geared motors are smaller and lighter, and they offer less resistance when you're pedaling. The direct drive motors are bigger, and can be more powerful, but are heavy and have more pedaling resistance. If you're going for a power-assist strategy, where the motor is there to help you out, the slightly more expensive geared motors are the way to go. If you're looking for a high-powered ride that you're probably not going to pedal much, one (or two) of the larger direct-drive motors will give your bike more of a motor-scooter/moped feel.

There are some motors that ride "outboard" of the wheel, but they're fading from the market. These also require a special wheel, with a separate drive gear for the motor on the bike hub, and are generally cheaper than a hub motor. They're bulkier, not as powerful, and add weight on the left side of the bike, not the center. With the progress being made in hub-motor development, they're not as attractive an option for a daily ride.

Motors' maximum speed is determined by the voltage—the higher the voltage, the faster the motor will spin. A 48-volt motor will have a higher top speed than a 36 V motor (typical voltages for electric bike kits), but a 48 V motor needs more battery cells to produce that speed. If you're looking for a simple assist, 36 V is fine; if you're looking for scooter-like performance, you're going to want a 48 V kit.

The second critical rating is the motor's power capacity, rated in watts. This will tell you how much weight it can pull and give you a pretty good idea of top speed and acceleration. The smallest motors you'll see on an electric bike are around 250 W, and will give you a gentle assist. More typically, you'll see a 300 to 350 W motor. The biggest hub motors are in the 1,000 W (1 kW) range, giving them a performance more like a true moped or motor-scooter.

When making the motor choice, you can choose rear or front mount. Typically, you want to mount the motor on

Dual 1,000 W Golden hub motors give near-motor-scooter performance.

Battery Types & Capacity

Sealed Lead-Acid	Performance	Weight / Size	Cost
Below 10 Ah	Strictly power-assist, limited range	Light/small	Lowest
10-15 Ah	Powered, limited range	Moderate/moderate	Low
15+ Ah	Powered, 20+ miles range with pedaling	Heavy/large	Moderate
Lithium-Ion			
Below 10 Ah	Strictly power-assist, limited range	Ultralight/small	Moderate
10-15 Ah	Powered, limited range	Light/small	Moderate to high
15+ Ah	Powered, 20+ miles range with pedaling	Moderate/moderate	High

A rack-mounted lithium-ion battery pack.

the rear wheel to maintain the balance of the bike. The only time you'd stray from that is if you're running a very small motor, or your bike won't accept a rear wheel replacement. For instance, some bikes are equipped with 3- or 5-speed rear hub gears. In that case, if you put in a rear hub motor, you'd lose your gearing.

Brakes can also be a complication. Most hub kits have options for wheel-caliper or disk brakes, but keep this in mind when you're making your decision—make sure your brakes are compatible. Almost all hub motors will fit in the axle space on a standard frame (100 mm front, 135 mm rear).

Batteries. Batteries are the oomph behind the motor, possibly the single-most important factor in the bike's performance and cost. Two basic choices are available—lead-acid (L-A) and lithium-ion (Li-ion), a term covering a range of lithium-based chemistry. For the L-A choice, sealed batteries are usually used—they don't need maintenance and they won't leak if mounted on their side or tipped over. They're low-cost but heavy for the amount of energy they provide. NiMH (nickel metal-hydride) is a choice you may see on occasion. Their weight-to-capacity ratio is somewhere between L-A and Li-ion; they were a common option a few years ago before Li-ion technology was readily available.

For the same capacity (rated in amp-hours, Ah), Li-ion battery technology is usually half the weight of a L-A battery—but they're typically about twice the cost. Li batteries have greater longevity, so they won't need to be replaced as often, and the lithium is not as toxic as lead, although a little more difficult to recycle. You'll want a battery that provides 10+ Ah, no matter which type you choose.

When weight-saving is important, Li-ion is clearly the best choice if it fits your budget. The good news is that the system is completely "battery agnostic"—that is, you can switch battery types at any point without having to make major changes in the system or design. You can add more batteries, you can change battery type, you can even switch between several types of packs as easily as you can remove and replace the pack, as long as the voltage is the same—for most systems, either 36 V or 48 V. It's not at all unusual for people to start off with L-A packs and then upgrade to Li-ion when it is time to replace the pack.

Controls. The motor controller is the little electronic box, usually about the size of a box of wooden matches, that controls your speed. Usually, the controller is mated to the motor, because it has to match with the motor type and

A thumb speed control.

A motor speed controller.

voltage. It's the one component that is a little touchy, and where you're likely to get failures if you get them at all. Buy your controller and motor together, and make sure they're right for each other. When you're assembling your bike, mount the controller in as dry, cool and vibration-free a place as you can, such as on the center tube or luggage rack, and away from the wheels and fenders. One company, Golden Motor, goes so far as to mount their controller *inside* their hub motors—a great way to protect them from moisture and a good way to ensure a match between the motor and controller.

Rider controls are pretty simple—a throttle, usually a twist-grip or a thumb lever and, sometimes, cutoff switches in the brake levers to ensure you're not braking against the pull of the motor. A good kit will have rider controls that will blend nicely with the stock controls of the bike.

What's Available

Each manufacturer has a range of price and power options, as demonstrated in the "Kits" table. One of the best online sources of information is from www.electric-bikes.com, but I leaned heavily on a local dealer, Paul Morlock of Electric Bikes of New England. Not only did he have some great products in stock, but he also had the experience to offer some great advice.

Almost every package is based on products that originate from China, and some suppliers ship directly from China, which can take weeks, if not months, to arrive. You may get great support, or not…there's no way of knowing. Returning defective parts can become a nightmare. There are several knowledgeable dealers around the United States, that have invested their time and resources to make sure they're selling you a good product and will back them up.

In ordering my E-BikeKit, which was shipped to me from Electric Bikes of New England, the dealer made a simple mistake—he specified the wrong wheel size, which we didn't realize until I started the project. A quick call to him and, before I knew it, an order was placed for the correct wheel, to be shipped directly to me. It came the next day, along with a prepaid UPS label to return the first wheel. I also had one technical question and received the answer within 15 minutes of sending my e-mail. Product support is crucial.

Skills & Tools

You'll need to approach this project with a good understanding of bicycle mechanics, for your own peace of mind, and also for your own safety. You're mounting some substantial hardware to your bike that can affect its balance and structure. Your gear shifting and braking may be affected, and, especially with the 200 to 1,000 W of additional power, you need to be confident that everything can take the added forces.

If you're a competent bike mechanic, you should be able to do this. If not, at the very least, take your conversion to a good bike shop for a safety check and tune-up before you hit the road.

Some Common Electric Bicycle DIY Kits

Manufacturer	Power (W)	Standard Battery	Price (MSRP)
Currie Electro-Drive	450	SL-A	$400
	250	Li-ion	1,000
	500	Li-ion	1,300
E-BikeKit	500	SL-A	584
	350	SL-A	584
Crystalyte hub motors	900	SL-A	1,140
	900	Li-ion	1,830
	1,440	Li-ion	1,940
	2,880	Li-ion	2,950
eZeebike hub motor kits	350	Li-ion	1,200
BionX hub motor kits	250	NiMH	1,200
	350	Li-ion	1,800
Golden Motor	1,000	Li-ion	980

For a more complete list see www.electric-bikes.com/bikes/kits.html

No special tools beyond those for basic bike maintenance are usually needed—wrenches for tightening axle nuts, Allen wrenches, screwdrivers, and pliers. It doesn't hurt to have a multimeter handy. I used mine to check the battery output and connections before connecting the controller, and, if things aren't working right, you can check continuity. Some wire loom, vinyl electrical tape and insulated heat-shrink tubing (along with a heat gun) will make it a professional-appearing job.

Customization may require more skills and tools. I made some aluminum brackets in my machine shop, to give me a professional-looking, solid battery mount. This isn't necessary, but it was a fun part of the project for me. None of the kits require fabrication skills or modifications to the bike frame structure.

After a lot of research and considering my needs, I chose a 350 W geared rear-hub motor kit from E-BikeKit. It has plenty of power as an assist, allows easy pedaling,

(continued on page 91)

The E-BikeKit comes with the motor (the wheel shown in the box) and controller. The battery (the silver tube), charger, and rack came separately.

Step by Step

The Layout

I started by mounting the rack I purchased separately, and the optional bicycle center stand, which allows the bike to stand upright with its nearly 20 pounds of batteries mounted on the rack—a high center of gravity. It also makes the bike easier to work on. I flip the stand down, and the rear wheel lifts off the ground, so the wheel can be removed and replaced without having to use a bike work-stand or turn the bike upside-down. If your kit doesn't come with a center stand, I'd highly recommend it as an additional purchase.

The next step is mounting the battery and controller. Some batteries are designed to integrate into the frame, but often need a frame designed specifically for them. The battery I bought was designed to mount on the down tube, but since the bike has a very narrow center, it wouldn't fit there. Top bar mounting is a possibility, but I chose to mount it on the rack. Rack mounting is common, but it places all the weight at the rear of the bike, whereas mounting within the bike's center triangle both distributes the weight and keeps the center of gravity lower.

I started by placing the battery case and controller in roughly the spot I thought it should be. Take the time for careful consideration—there are lots of ways you could set this up, and sometimes it takes a few attempts to get it just right. Think about things like switch and cable access; exposure to rain, dust, and dirt; and the balance of the bike. Make sure the wires are long enough to reach their destinations.

A center stand, which keeps the bike upright and balanced when you're not riding it, is a good investment.

Although the battery pack can be mounted on the down tube or the top bar, mounting it to a rear rack is an alternative.

Before you bolt anything down, carefully consider the placement of the battery and controller to make sure that neither they, nor the wiring, will interfere with the bike's operation.

Assembly

Once you're satisfied with the component layout, mount the hardware. For this project, mounting the thumb throttle on the left hand grip made sense, since my only gear-shifter is on the right-hand side. Next, unmount the original wheel and tire, and mount the tire on the new wheel.

Then ease the new wheel into place, making sure to route the chain around the gear cassette and tighten the axle nut. Re-attach the brake cables now—don't put this off. They're too important, and they're easy details to forget later on, especially once you're all excited to go for your first ride.

The E-BikeKit instructions suggested using cable ties, those little plastic strips, to hold the controller in place. However, I preferred to fabricate a more secure mount with screws and nuts. I cut out the mounting bracket from some scrap aluminum for both the controller and the battery.

Once everything is mounted, route and secure the wiring. Keep it neat and tidy to make it easier to trace if you need to do some troubleshooting, and to avoid wear due to repetitive rubbing and kinking. Use electrical tape or heat-shrink tubing to make tight, weatherproof connections.

Most of the control wiring from the throttle and the controller isn't dangerous, but will cause problems if damaged. The main power connections from the battery, and to the motor, are a greater risk. Be very careful handling these, and avoid shorting them. If you're not confident in your electrical skills, find someone who can inspect your work before going "live."

For the connector on the battery, and the wires going to the controller, the cables need to be cut and soldered. Since I used a battery pack from a different manufacturer, I had to fabricate this connection—a soldered wire splice with heat-shrink tubing insulation. The wiring is safer, more reliable, and easier to troubleshoot if it's laid out nicely, secured well, and protected from the elements. It will pay to make this installation as professional as you can.

Because of the relatively large axle hardware—to keep the wheel from spinning the axle—it may be easier to completely remove the nuts and washers from the axle before fitting.

When determining mounting position, especially consider accessibility, such as being able to easily remove the battery from its holder for charging.

These secure and waterproof connectors are easy to connect by matching the arrows on each mating pair.

Off-the-shelf, plastic wire loom from an auto parts store helps organize the battery cabling.

DIY Troubleshooting

After finishing, but before you go on a test ride, check all of the cables and connections. Many times I've solved people's computer and printer problems by simply asking them to make sure the thing is plugged in.

I had everything wired together on my bike and flipped the switch. Nothing. Immediately, I assumed I had a bad controller or motor, but once I settled down I started tracing wiring. I unplugged the (very firm) throttle connector, and plugged it in again. Bingo. It ran like a charm.

If your system doesn't work, give everything a once-over and double-check every connection. Possibilities are sometimes a bad controller; rarely a bad motor; and maybe a defective throttle. The throttle is easy to test. Most kits come with two—a twist grip and a thumb lever—so it's just a matter of switching throttles and trying again. But 90% of the time, the problem will be a connection.

and has a small, unobtrusive hub motor. E-BikeKits usually come with an SL-A battery pack in a heavy nylon fabric case, but we purchased a 36 V Li-ion pack. The battery is housed in a round aluminum cylinder that can be mounted on the down tube. It has 10 Ah of capacity at a good price. The bike is a Felt Café women's bike, which has a derailleur-type 7-speed hub—a perfect match for our E-BikeKit, thanks to some great advice from the folks at the bike shop.

The Ride

Naturally, I couldn't wait to try out the bike with a little test ride. That test ride turned into a ride all over the neighborhood, then all over town. I literally couldn't stop smiling, and never broke a sweat. About a half-dozen people wanted to give it a try, and one friend in particular couldn't stop hooting and giggling. It even passed the "teenager test"—my 17-year-old son loved it.

In all, it was a project that was thoroughly enjoyable, both in the build and the result. It is, without a doubt, the first in a series of conversion projects—in fact, the teenager wants to convert his Schwinn Stingray to a 500 W hub motor. The time it took, not counting my bracket fabrication, was about three hours, including "sittin' and thinkin'."

If the DIY electric bike building bug bites you, one of the most impressive resources on the web is the Endless Sphere forum (see Access). There, you'll find everyone from the greenest "noobs" to experienced builders who are designing and making their own frames, electronics, and even motors for electric bikes.

Access

Ted Dillard (ted@evmc2.com) is the author of www.ElectricChronicles.com, a website devoted to two-wheel electric vehicles of all descriptions, renewable energy and EV technology; and of "…from Fossils to Flux," a basic guide to building an electric motorcycle. He's had an unhealthy obsession with EVs since his first ride in a Renault Mars II in 1968.

Electric Bike Choices

Motor Type / Power Rating	Characteristics	Total Load (Lbs.)	Applications
Geared, 250 W	Light, spins easily when pedaled	150	Power-assist pedaling, flat-terrain, paved
Geared, 350 W	Light, spins easily when pedaled	180	Power-assist pedaling, mixed-terrain, paved, extended use
Direct, 250 W	Light, less expensive	150	Power-assist pedaling, flat-terrain, paved
Direct, 350 W	Light, less expensive	180	Power-assist pedaling, mixed-terrain, paved, extended use
Direct, 500 W	Moped/scooter performance, heavier	200	Powered ride, moderate speeds, mixed to hilly terrain, paved
Direct, 750 W	Scooter/light motorcycle performance, near sustained 30 mph top speeds, heavy to pedal	250+	Fully powered ride, high speeds, hilly terrain, off-road
Direct, 1,000 W	Scooter/light motorcycle performance, sustained 30+ mph top speeds, heavy to pedal	250+	Fully powered ride, high speeds, hilly terrain, off-road

A special thanks to the dealers who helped with this project:

East Coast Alpine • www.eastcoastalpine.com

Electric Bikes of New England • www.ebikesofne.com

Hollywood Electrics • www.hollywoodelectrics.com

Kit Manufacturers:

BionX • www.bionx.ca

Crystalyte • www.crystalyte.com

Currie Technologies • www.currietech.com

E-BikeKit • www.e-bikekit.com

eZee •www.ezeebike.com

Golden Motor • www.goldenmotor.com

Other Resources:

Electric-Bikes.com • www.electric-bikes.com

Endless Sphere forums • www.endless-sphere.com

Leasing the Sun

by Kelly Davidson

Considering a solar lease? Here’s what you should know before signing on the dotted line.

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With low or no up-front costs, solar leases are increasing in popularity among homeowners who can’t afford to purchase a PV system outright or don’t want the burden of ownership and maintenance. But the concept is still relatively young and not all of the kinks have been worked out.

Being able to recognize a good deal, or a bad deal, is an important part of successful solar leasing. It’s all about the “fine print.”

Between the Lines

So what should you look for—or look out for—in a contract? It would be due diligence to talk to your attorney and accountant before signing a lease. Alternatively, you could solicit contracts from multiple vendors and compare the verbiage (see “Before You Sign” sidebar).

Make sure you understand the type of agreement you’re considering. There are different types of “leases”—some are true leases and some are power purchase agreements (PPAs). With a solar lease, you lease the solar equipment; with a solar PPA, you are only paying for the energy the system generates. In both cases, the PV system installed on your home is owned and maintained by the lease or PPA provider, and is connected to the grid so you can buy any additional energy you might need from the utility.

Your paramount concern should be whether the contract can be amended and what, if any, rights you have in those cases. There are cases where lease companies have amended the original terms and raised rates for one reason or another—if the contract allows amendments, then you might have no recourse and have to take whatever comes your way. Most contracts, even those outside of the solar market, have a clause that stipulates the contract can be transferred in certain events, such as the company’s sale, bankruptcy, or dissolution. The legalese tends to be too complex for the average homeowner to understand, and the devil is in the details as to what that clause might mean for you down the line. In most cases, the PV system cannot be repossessed, and the homeowner cannot be held liable for the company’s debt.

When evaluating any solar lease, keep your expectations in check. Often, the investment rate of return on buying a system outright is substantially higher. After paying for the lease payment and accounting for any extra power you might buy from the utility, the savings on a solar lease are somewhat

small, usually $20 to $50 per month. However, those savings might increase over time as electricity rates rise—plus, there is the potential savings that come from having a third party monitor, maintain, and guarantee the system.

Choose Wisely

When evaluating a solar leasing company, take your time and consider all available information and choices before signing—it's a long-term relationship and by no means a small decision. Don't be pressured into signing a contract, such as being threatened by losing out on government incentives for not acting quickly.

A good starting point is the company's track record. How long has the company been in business, what kind of reputation does it have, and how many leases have they sold? Most lease companies are only a few years old. The biggest and oldest probably have made more than 10,000 leases and, in the process, worked out a lot of kinks. New leasing companies are showing up regularly, and while some of these might end up being real winners, apprehensive consumers may want to stick with more established companies.

Another factor is how long the company's program has been active in your state. Many of the larger companies have started leasing programs in one state and branched out into other states. While participation is necessary for these programs to grow and survive, you may not want to be a guinea pig for a company navigating the incentives and guidelines in a new territory. Sure, you might get a more favorable deal, but the trade-off may be long lead times on installation, potential administrative snags, and/or undeveloped customer relations. While a contract protects you, it is important to remember that it is only enforceable if you are willing to take legal action.

A key consideration in selecting your leasing company is the PV system installer they use. There are essentially three types of solar lease companies: stand-alone financing companies that partner with installers; module manufacturers that offer leases through a network of independent dealers; and full-service shops that provide everything—financing, design, installation, and monitoring.

Depending on which company you choose, you may have little control over which installer you work with. Some companies pick an installer for you, and there could be a wide range in capability. For any solar energy project, you should work with a licensed and qualified installer. Just as you would with any contractor, be thorough and ask the right questions.

- Does the installer have the required licensing for your area? (Ask for proof.)
- Which products does the company use?
- Does the installer use subcontractors, or their own installation crew?
- How long has the company been in business, and what certifications (such as "NABCEP PV Installer" certification) does its staff have?
- Can the company provide references from other homeowners?

You also should ask how the installer assesses a project and designs a system. The installer should first discuss the project and your energy needs, and then survey the roof, identify shading issues, determine the amount of energy that can be anticipated from an installation, and lastly, specify a system and lease.

The most expensive way to get solar is to do nothing now and wait until all of the incentives are gone.

So, if you can't buy with cash, take out a loan. If you can't get a loan, do a good lease or PPA.

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Lease, Finance, or Buy?

Industry Experts Weigh the Options

Jason Coughlin is an analyst with the National Renewable Energy Laboratory in Golden, Colorado. His work focuses on financing PV systems such as third-party financing models and municipal financing mechanisms.

Residential solar leases and power purchase agreements (PPAs) can significantly reduce, if not eliminate, up-front costs to homeowners. Under a solar lease, the homeowner makes monthly lease payments that are offset by electricity bill savings. Under a PPA, the homeowner purchases the electricity generated by the PV system. In both cases, the homeowner continues to make monthly payments to the local utility for additional electricity needed. At the end of the contract term, the homeowner normally has three options: purchase the system, extend the contract, or request that the system be removed.

In addition to third-party finance options, there are other non-mortgage options for purchasing a PV system—dealer financing and unsecured loans. In all cases, the credit quality of the homeowner is considered. Availability, and terms and conditions for all of these financing options can vary. The U.S. Department of Energy's *Homeowner's Guide to Financing a Grid-Connected Solar Electric System* offers more information (www.nrel.gov/docs/fy11osti/48969.pdf).

Andy Black is the CEO of OnGrid Solar, a solar-electric financial analysis and sales software company. He teaches sales, marketing, economics, and financing classes nationwide.

The least-expensive way to get a PV system is to pay cash. This way, you keep all of the benefits. The second least-expensive way is to take out a home-equity loan, which typically has low, tax-deductible interest. In this case, you pay interest on the loan, which shares some of the energy savings with the bank. If the cost of the loan payment after factoring the tax deduction for the loan interest is less than the savings on your electric bill, then you are way ahead—in a few years, you will own the system outright and no longer have a loan payment.

The third least-expensive way to get a PV system is a lease or a PPA. Your monthly cost will usually be more than a bank loan payment because you are now sharing the benefits with at least two other parties: the company providing the lease/PPA services and the investor/bank funding them. Generally, the more parties involved, the less the customer's benefit will be. Some lease/PPA monthly payments may match or even be below the loan's cost, but remember, once the loan is paid off, *you* own the system. At the end of the lease/PPA term, you'll have the option to buy the system at fair market value. By then, there will likely be no incentives available, but the cost should be substantially lower than a new system.

This cost/benefit trade-off makes sense in another way—with cash, the homeowner takes on all of the risk. With a loan, the bank is taking a little bit of risk. With the lease/PPA, the provider is taking anywhere from a lot to almost all of the risk on the deal. The more risk one takes, the more they expect to be rewarded.

The most expensive way to get solar is to do nothing now and wait until all of the incentives are gone. So, if you can't buy with cash, take out a loan. If you can't get a loan, do a good lease or PPA.

Tom Konrad is a financial analyst and portfolio manager specializing in renewable energy and energy-efficiency investing. He blogs about clean energy stocks at www.altenergystocks.com and *Forbes*, and is a member of the Northeast Sustainable Energy Association finance committee.

Even if you can secure other solar financing, a PPA or lease is worth considering. Although raising your own financing is usually cheaper in the long run, if you don't want to worry about maintenance and repairs, the turnkey nature of these programs can be attractive.

This is also an advantage if you think you might sell your home, because the new homeowner may be less comfortable with solar technology and may like a third party to take care of everything.

The relative value of a lease or PPA depends on the particular terms, which are not uniform. I tend to prefer the PPA format because a PPA company makes more money as its systems produce more energy—an incentive to keep the systems operating at peak performance.

The simplest way to compare financial advantages is to use "internal rate of return" (IRR). This gives you the effective interest rate earned on your investment. If you had the choice of solar financing option A, with an IRR of 3%; option B, with an IRR of 2.5%; or keeping the money in the bank earning 2% interest, then you'd be better off with either solar option. Option A is better than B because it has a higher IRR.

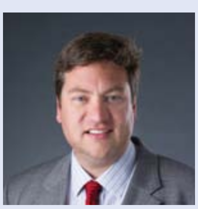
It's risky to rely upon the vendors' savings calculators to compare, because they will tend to use the assumptions that make them look best, so you would not be comparing apples to apples. To help, I put together an IRR calculator in a spreadsheet, which you can find in the Web Extras section of www.homepower.com.

Amy Heinemann is a policy analyst for the North Carolina Solar Center. Her work includes researching state, local, and utility incentives and policies for the Database of State Incentives for Renewables & Efficiency.

There is no "best" financing option for a residential PV system—it depends upon an individual's financial situation, motivations, and the incentives available. Many states, utilities, local governments, and nonprofits offer direct cash incentives (a grant, rebate, or performance-based incentive) to reduce the cost of residential PV systems—which may make buying outright an affordable option. State tax credits and deductions may further reduce the cost, as does the federal 30% tax credit, which is available to all U.S. taxpayers with a tax liability.

State loan programs may also be available, and some homeowners may be able to finance a PV system via a home equity loan. In addition, an innovative financing mechanism called Property Assessed Clean Energy (PACE) program, is available in a handful of jurisdictions (see "Keeping PACE").

If a homeowner cannot buy or finance the up-front cost of a PV system, third-party, or retail, PPAs are available in 21 states. Where PPAs are unavailable, solar companies may offer leases instead. With a lease, you'll pay per kilowatt (kW) installed. With a PPA, you pay per kilowatt-hour (kWh) generated.



Tom Kimbis is the director of policy and research and is general counsel for the Solar Energy Industries Association (SEIA) in Washington, D.C. He develops long-term policies for promoting solar energy and oversees expansion of SEIA's market research.

New financing methods are making solar more affordable and available. Solar financing choices are now similar to options for buying a new car or home. Homeowners have to look carefully at their individual financial situations. For some, the cash or financing option makes sense—you're buying your electricity up-front for decades, and lowering or eliminating your utility bill. Recent studies show that PV systems boost home resale value—a Lawrence Berkeley National Laboratory study released this year found that for a homeowner in California, an average-sized, relatively new PV system adds $17,000 to the sale price of a home.

Leases are also soaring in popularity. In 2011, more than a third of all residential installations in California and Colorado were leases. Just two years ago, only 10% of residential installations in California were solar leases, and there was no market for leases in Colorado just a year ago. With many of the same benefits as purchases, but avoiding the up-front cost and maintenance, solar leases will continue to be attractive to homeowners.

As with any major home improvement project, do your homework. Ask contractors about their experience installing PV systems and check references. But no matter the financing mechanism, the decision to go solar can be cost-effective.

What Makes a Good PPA or Lease?

So you can compare programs, get multiple bids. In most parts of the country, there are enough lease and PPA companies to enable you to review at least three potential contracts. Then analyze the following points:

- **Payment escalation rates.** Over the last 20 years, the national average electric rate increase has been about 2.5% per year. Make sure that the contracted rate of increase for the system's payments is no more than 4%. Do the computations to make sure that your payments will remain reasonable through the term, which may be 10 to 20 years.

- **End-of-term provisions.** Make sure the buy-out at the end of the term is an option, not a requirement, in case you don't like the offered price. This allows you to negotiate based on what a new, replacement system would cost. Make sure that if you request the system be removed, they will do so at no cost and agree to restore your roof to good, attractive condition—with the exception of unavoidable fading of the roof where not covered by the PV array.

- **Midterm transfer/buy-out terms.** The agreement should allow you to sell the home and transfer the system contract to another party if they can meet the credit standards. It should also allow you to pay off and terminate the agreement for a reasonable price—either with retention or removal of the system—if your home buyer doesn't qualify for or doesn't want the system. Make sure there are no "hidden" transfer fees.

- **Reasonable performance guarantee.** The system should be guaranteed to perform within a few percent of what the NREL's PVWatts calculator shows—unless it can be shown to be different due to shading, local climate, etc. (See www.nrel.gov/rredc/pvwatts/.) Evaluate the terms of maintenance, repairs, and system monitoring. What maintenance will be your responsibility, and what will be managed as part of the agreement? What specific services are you entitled to, who performs the services, and what kind of replacement equipment can be used should your system require it?

- **Insurance.** Some companies require you to add the system to your homeowner's insurance. If so, talk with your insurance provider before you sign, and understand the costs and coverage.

These "reasonable" requests will keep the customer in control and the contract flexible, making a higher-quality lease agreement. In return, the customer should expect to have higher monthly lease/PPA costs when compared to a cheaper, inflexible (i.e., risky) lease or PPA.

—Andy Black

Leasing Companies

Company	Availability	Background	Network	Offerings: Purchase	0% Down Lease	Down Payment Lease	Prepaid Lease	PPA	Home Equity Line of Credit
BrightGrid www.brightgrid.com	AZ, CA, CO, HI, NJ	Began offering residential leases in March 2010. BrightGrid's leases are available through a network of independent PV equipment manufacturers and dealers, and backed through "traditional tax equity funds and other internal funding."	More than 24 approved installers. The homeowner goes through the local or regional installer, and BrightGrid underwrites the lease agreement. BrightGrid manages the lease, including coordinating any maintenance and repairs through the original installer.		✓	✓	✓		
Centrosolar www.centrosolaramerica.com	AZ, CA, NJ	Centrosolar America, owned by the PV manufacturer Centrosolar Group, began offering leases for its complete system kits in 2011. The leases are underwritten by and have fund administration by BrightGrid (see above).	Centrosolar has more than 200 installers signed up on its national network, but only a select group offer the CentroLease. The partner installers are responsible for the operations and maintenance warranty, while Centrosolar is responsible for the equipment warranty.	✓	✓	✓	✓		
Clean Power Finance www.cleanpowerfinance.com	CA	The company began offering leases in April 2011 and acts somewhat like a silent partner, which is why its name is not widely known. Local installers offer CPF financing options but retain their local brand. The installer handles customer relations, while Clean Power Finance powers the behind-the-scenes transaction.	More than a dozen installers offer leases through Clean Power Finance.	✓	✓	✓	✓	✓	✓
SolarCity www.solarcity.com	Most parts of AZ, CA, CO, DC, HI (Oahu), MA, MD, NJ, NY, OR, PA, TX	SolarCity introduced its solar leasing program in April 2008 and has almost 12,000 lease customers. The company's leases are backed by private funding totaling $1.4 billion. The $280 million Google-backed fund, which was announced in summer 2011, is SolarCity's largest and its first collaboration with the Internet giant.	Based in San Mateo, California, the company employs approximately 450 installers in 24 operations centers in 11 states. Each center provides local sales and installation.	✓	✓	✓	✓	✓	
Solar Universe www.solaruniverse.com	Tempe, AZ; various: CA; Springfield, IL; Slidell, LA; Brick, NJ; Las Vegas & Reno, NV; Mountain Top, PA	Solar Universe got its start in 2008 with the opening of solar installation franchises in the San Francisco Bay area. With $7 million in financing, the company introduced a lease program in 2011, which has generated 100 residential leases so far. More funding is expected.	Headquartered in Livermore, California, Solar Universe provides installation through 23 individually owned and operated franchisees in eight states.	✓	✓	✓	✓		
SunCap Financial www.suncapfinancial.com	AZ, CA, CO, NJ, NY, PA, TX	Houston-based SunCap Financial is owned and backed by energy wholesaler NRG Energy and acts as a go-between, connecting partner installers with the capital funds for residential leases. SunCap began offering solar leases in March 2011, and has sold approximately 1,000 leases. Its leasing program is backed by funds with the National Bank of Arizona and Amegy Bank.	More than 150 installers in seven states offer leases through SunCap Financial. The installer originates the relationship with the homeowner, and SunCap provides operations and maintenance for the duration of the lease.		✓	✓	✓		
Sungevity www.sungevity.com	AZ, CA, CO, DE, ME, MD, NJ, NY	Sungevity launched its residential solar lease program in 2010, and has backed leases for approximately 2,000 PV systems.	Approximately 200 independent installers offer Sungevity leases. The company contracts directly with homeowners and oversees its projects for the duration of the lease.	✓	✓	✓	✓		
SunPower us.sunpowercorp.com	AZ, CA, CO, HI, MA, NJ, NY, PA	SunPower Corp. is a PV manufacturer that began offering a lease program in 2009. In July 2011, the company created a $105 million fund to expand the lease program.	Based in San Jose, California, SunPower offers a lease and other financing options through about 400 independent dealers in the United States.	✓	✓	✓	✓		
SunRun www.sunrunhome.com	AZ, CA, CO, HI, MD, MA, NJ, OR, PA	Based in San Francisco, SunRun began selling residential leases in 2007, having issued about 14,000 leases and raising financing for more than $750 million in solar installations.	A customer will be matched with one of 25 installers in nine states. SunRun manages the lease for the term, including system maintenance and monitoring.	✓	✓	✓	✓	✓	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Keeping PACE

by Kelly Davidson

Beyond leasing, another program that's helped property owners fund energy-saving improvements is the Property Assessed Clean Energy (PACE) program. This financing method gives homeowners the option to pay off the costs through surcharges on their property taxes, which are assessed over the course of up to 20 years and stay with the home even if it is sold.

As part of the American Recovery and Reinvestment Act of 2009, the PACE program is backed by more than $150 million in federal stimulus funds and overseen by the U.S. Department of Energy—though individual programs are administered by local jurisdictions.

The Structure of PACE

PACE programs have long-enough payback periods to keep the utility savings greater than the monthly payback amounts—but short enough so that the project will continue to produce savings after it is paid off.

While interest rates on PACE assessments are equal or higher than those on home equity loans, PACE requirements tend to be more lenient. Banks might require a homeowner to have at least 20% equity in the property, whereas equity requirements for PACE assessments tend to be lower—in some cases, homeowners may only need to match the loan amount dollar-for-dollar in equity—so $5,000 in equity for a $5,000 assessment.

Halting the PACE

Over the past two years, 27 states and the District of Columbia have passed laws allowing their local governments to administer PACE programs. Yet virtually all programs came to a halt last year when Fannie Mae and Freddie Mac discredited the PACE program in letters sent to lender groups around the country.

The government-chartered mortgage giants, which are involved in underwriting 90% of all mortgages in the country, warned that PACE assessments were violations of mortgage terms and could be grounds for foreclosure. Mortgage regulators at the Federal Housing Finance Agency (FHFA) followed up with a statement that directed Fannie Mae, Freddie Mac, and the Federal Home Loan Banks to reduce and restrict underwriting of mortgages with PACE assessments.

As a result, some lenders now require homeowners to pay off any new or existing PACE assessments prior to refinancing or selling their homes—instead of allowing them to transfer ownership, similar to other property assessments.

Without transferability, PACE has lost much of its value as a market driver, according to Jason Coughlin, a solar-market analyst with the National Renewable Energy Laboratory in Golden, Colorado.

"A stumbling block [for solar adoption] has been that most people move on average every five to seven years and haven't wanted, or rather couldn't justify, the up-front costs when they knew they would move before realizing the payback," Coughlin says. "The appeal of PACE programs was that homeowners only pay for the project while they're in the home. When the house is sold, the next buyer picks up both the benefits and the costs associated with it. Under the current guidelines imposed by the FHFA, that is no longer the case."

The FHFA's declaration put PACE programs, both existing and planned, on hold and prompted several entities—including the state of California, Sonoma and Placer counties, the city of Palm Desert, and the Sierra Club—to file lawsuits against the FHFA.

In August, U.S. District Judge Claudia Wilken of the Northern District of California found that the FHFA had ignored its formal rule-making procedures when it issued the letters. As a result of the California ruling, the FHFA now will have to hold a public notice and comment period, and address any comments by either modifying the PACE ruling or justifying its unwillingness to do so.

The California judgment comes after rulings by two judges in New York favored the FHFA, dismissing similar challenges filed by the Town of Babylon on Long Island and the Natural Resources Defense Council. Both groups are appealing those rulings. Another lawsuit filed by Leon County in Florida is currently moving through the state's federal court.

Taking Action

In response, Congress has introduced the PACE Protection Act. If passed, this act would force the FHFA to rescind its warning and prohibit lenders from discriminating against homeowners and communities participating in PACE programs.

The legislation addresses the concerns of the FHFA by calling for more stringent underwriting criteria, consumer protections, and measures to reduce the risk and financial exposure to mortgage holders. It also clearly defines PACE as an assessment, not as a loan—a key point to the FHFA's position on senior lien status. Key provisions would standardize equity requirements, asking homeowners to hold at least 15% equity in their properties, and limit the size of projects to 10% of a home's value.

Take Action!

Think the PACE program is a good idea? Visit the PACENow website to send your Congressperson an automated letter: www.pacenow.org.

Whether the new terms will satisfy the Federal Housing Finance Agency remains to be seen. The bill is under House committee review and expected to be introduced in the Senate in the coming months.

Senior Status

In most jurisdictions, PACE assessments, like other property taxes, are secured by a lien on the property that ranks senior to the first mortgage. If a property owner fails to pay property taxes, the county can foreclose on the property to collect delinquent taxes. In most cases, however, the delinquency is paid off prior to foreclosure.

The majority of state legislatures gave PACE liens senior status in their respective authorizing bills, since most local governments cannot secure funding at competitive rates without it, says Amanda Vanega, a policy analyst at the North Carolina Solar Center.

"Senior lien status is a strong guarantee, the strongest, that the money would be paid back in the event of a default," Vanega says. "Banks see the PACE program where the PACE lien has senior lien status as low risk and provide local governments funding at a relatively good rate, and then the local government can, in turn, offer decent terms to participating property owners."

Federal housing officials maintain that the property liens and tax assessments used by PACE programs put lenders at risk in the event of a mortgage default. "The FHFA acts as if the PACE program is reinventing the wheel, but a senior special tax or assessment lien is an exceptionally common practice in the United States," says Adam Browning, executive director of the VoteSolar Initiative, a San Francisco-based advocacy group.

The country has more than 37,000 special assessment or special tax districts, which have been used to finance projects including street paving, parks, open space, water and sewer systems, street lighting, and seismic strengthening.

The FHFA's concerns that PACE financing creates additional risk for mortgage holders and homeowners are "completely unsubstantiated," says Gina Lehl, a manager with the Sonoma County's Energy Independence program, which is among the few PACE programs still active in the country.

"The default rate is very low, miniscule. The people that participate in these programs tend to be more financially savvy and more conscientious," says Lehl, who won a grant to create a manual for other California jurisdictions to use in replicating the program.

The program's data bears this out: PACE properties have mortgage default rates that are 30 times lower than average. According to David Gabrielson, executive director of the advocacy group PACENow, a survey of program administrators found that there are only two known defaults of the nearly 2,500 existing PACE liens.

While the fight to restore PACE programs continues, the question remains whether the demand for PACE still exists. "If reinstated on a national scale, PACE programs must now compete with solar leasing options that were not available a year or so ago," Coughlin says. "The PACE window may have closed. Only time will tell."

Active PACE Programs

Wyoming, Massachusetts, Connecticut. All three states have passed the PACE-enabling legislation, even after the FHFA issued its guidance last year.

New York. The town of Babylon has kept up its Long Island Green Homes program, which focuses exclusively on funding energy-efficiency upgrades. Instead of annual property tax surcharges spread out over 20 years, fees are added to homeowners' monthly solid-waste bills and paid over an average of 8.5 years.

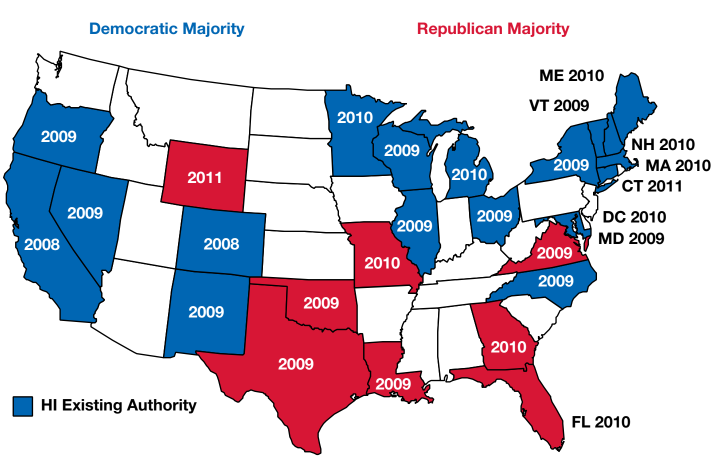
Wisconsin. In River Falls, the River Falls Municipal Utilities is still accepting applications for its Save Some Green program, which is 100% utility-funded and administered.

California. While Berkeley is credited with initiating PACE, Palm Desert is the city that amended California code to define rooftop solar and other energy-efficient home improvements as a public benefit that would qualify for assessment authority.

Palm Desert also recently committed initial seed funding of $25,000 to form a nonprofit education and advocacy organization for PACE, called Energy Independence America. Still in its infant stage, the group aims to enlist other cities and counties across the country in the effort to overturn FHFA's administrative action.

Colorado, Michigan, Ohio. Several commercial PACE programs are either operating or in the works in other jurisdictions as well—including Boulder, Colorado; Ann Arbor, Michigan; and the greater Cleveland, Ohio, area.

State Majority when PACE Legislation was Passed



CHARGE CONTROLLER
BUYER'S GUIDE

by Dan Fink

Any time the sun is shining, a PV array is ready to produce electricity. All that's needed to get the electrons in those wires moving is a complete circuit. But in off-grid battery-based systems, overcharging will occur if the batteries are full and if more energy is being generated than is being consumed by loads. This can permanently damage the batteries.

That's where controllers come in—to protect the batteries. The simplest PV controller is a manual switch that's flipped to disconnect the PV array when the battery bank is full. However, since battery damage can happen quickly, an automated solution is needed. Modern PV charge controllers can:

- prevent overcharging and coddle the battery bank with a strict regime of healthy charging cycles;
- equalize the batteries on a set monthly schedule or on command;
- log, store and send detailed charging information to a computer or the Internet;
- automatically control other equipment in the system according to battery bank voltage;
- and even communicate with other system components to deliver the best system performance.

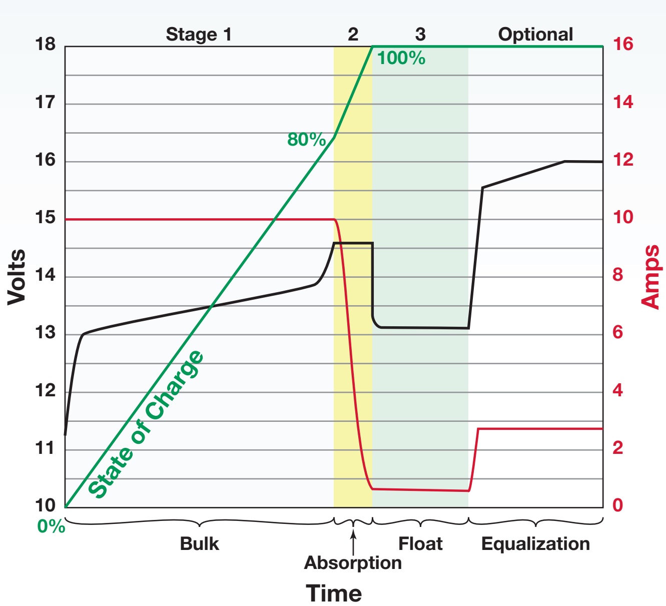
Advances in Controllers

The earliest PV charge controllers were voltage-controlled switches that disconnected the PV array when a certain voltage was reached. When voltage fell to another, lower point, it reconnected the array. These controllers protected the batteries from overcharging, but were unable to provide the three-stage charging regime recommended by battery manufacturers for longest battery life, since the controller output was either "on" or "off."

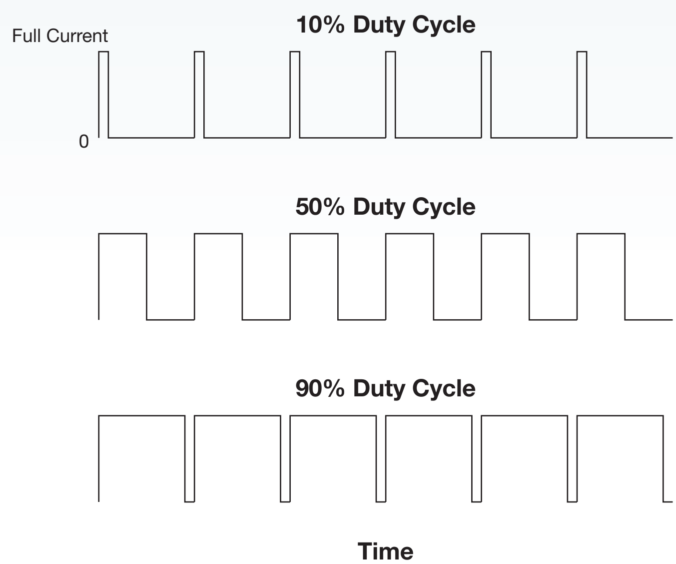
The advent of pulse-width-modulated (PWM) controllers made efficient three-stage charging from a PV array possible. This technology charges batteries with high-frequency electrical pulses, and can continuously change the amperage being delivered by varying the length of the pulses. When the batteries are discharged, the PWM controller senses this from the battery bank voltage and stays on to deliver the full current available, called the "bulk" stage of charging.

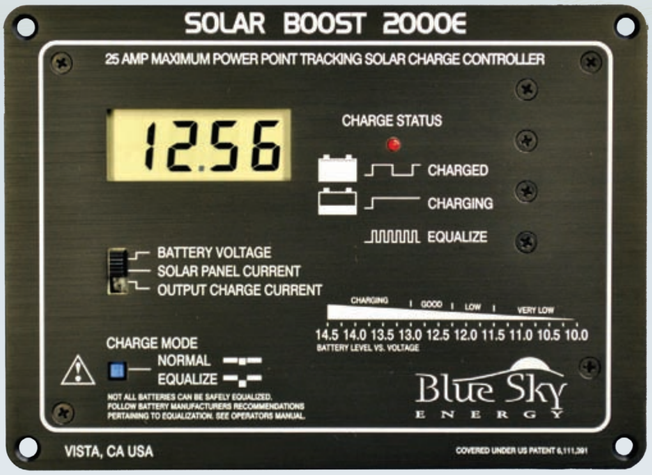
The next stage of charging is "absorption" and occurs as the batteries approach a full state of charge (SOC). The controller holds battery bank voltage constant for a period of time, and the "off" time of the pulses is increased to gradually reduce current as the bank is topped off.

SAMPLE THREE-STAGE CHARGING REGIME



PWM GRAPH





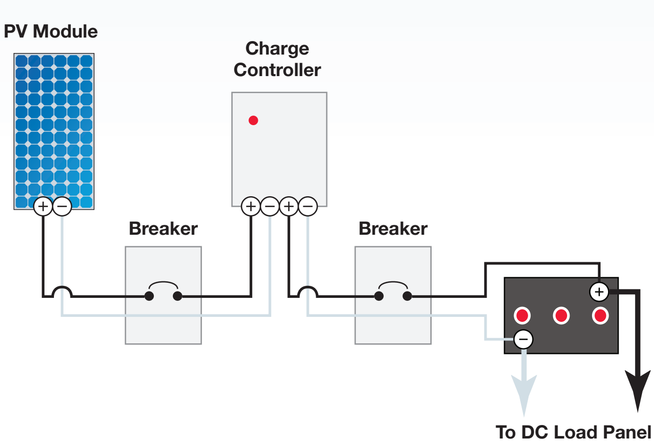
Blue Sky SB2000e

The "float" charging stage occurs when the batteries are full, and is sometimes referred to as "trickle charging." The battery bank receives just enough current to hold it at a constant voltage, but below the point where excessive gassing occurs. The gas produced is explosive hydrogen and gassing drops the electrolyte level in a battery, so it's critical to carefully control the float stage of charging. If the electrolyte level drops even slightly below the tops of the lead plates inside at any time, the battery will be damaged.

Controller set points for all three charging stages must be adjusted to the proper specifications for the battery bank type and voltage, and all of the controllers listed in the "Comparison" table allow some type of adjustment.

Flooded lead-acid batteries require regular "equalization"—a timed, controlled overcharge that extends battery life by stirring up stratified electrolyte, knocking sulfate deposits loose from the battery plates and bringing all cells in the bank to an equal SOC (Sealed batteries can be permanently damaged by equalization.) Some of the controllers listed allow users to program equalization on a time schedule. Be sure to check the specifications from your battery manufacturer and properly set your charge controller.

CHARGE CONTROLLER WIRING



Apollo Solar T80 MPPT

Diversion Control

Some charge controllers have a "diversion mode," where the controller is connected directly to the battery bank and sends a varying rate of amperage from the batteries to heating elements or other "dump loads." This is primarily used when wind or hydro turbines are connected to the system. They must *always* have a full load connected or they will over-speed, resulting in turbine damage. Air and water heaters are common dump loads, and DC water heater elements are available for all common battery bank voltages. Diversion mode is rarely used with PV systems, as the modules don't need to be always loaded.

Load Control

Some controllers have a "load control" mode, which is sometimes used as a "low-voltage disconnect" (LVD). When battery voltage drops below a certain point, the load controller disconnects DC loads from the system. This mode is used to prevent battery damage only in smaller DC systems, usually at remote, unattended installations, such as lighted billboards and communications repeaters. Some load controllers can also be used for automated backup generator starting and stopping.

Most controllers can't perform the functions of all these "modes" at one time—the controller must be set for PV control, diversion control, or load control—and that's all it can do.

Maximum Power Point Tracking

A newer innovation in PV charge controllers is called maximum power point tracking (MPPT). Computer-driven circuitry in the controller scans both battery bank and PV array voltages at regular intervals, and calculates the

CHARGE CONTROLLER* COMPARISON

Manufacturer	Model	Max. Amps	Max. Array V	System V
Apollo Solar www.apollosolar.com	T80 MPPT	80	140	12, 24, 36, 48
	T80HV MPPT	80	200	12, 24, 36, 48
Blue Sky Energy www.blueskyenergyinc.com	SB50L	50	57	12, 24
	SB3048L	30	140	24, 48
	SB3024iL	40	57	12, 24
MidNite Solar www.midnitesolar.com	Classic 150	96	150	12–72
	Classic 200	79	200	12–72
	Classic 250	63	250	12–72
	Classic 250KS	40	250	12–120
Morningstar www.morningstarcorp.com	TriStar MPPT 45	45	150	12, 24, 36, 48
	TriStar MPPT 60	60	150	12, 24, 36, 48
	TriStar 45	45	48N	12, 24, 48
	TriStar 60	60	48N	12, 24, 48
OutBack Power www.outbackpower.com	FLEXmax 60	60	150	12, 24, 36, 48, 60
	FLEXmax 80	80	150	12, 24, 36, 48, 60
Schneider Electric (Xantrex) www.schneider-electric.com	C-12	12	12N	12
	C-35	35	24N	12, 24
	C-40	40	48N	12, 24, 48
	C-60	60	24N	12, 24
	XW MPPT 60-150	60	150	12, 24, 36, 48, 60
	XW MPPT 80-600	80	600	24, 48

*Per *NEC* 690.4(D), this table includes charge controllers listed to UL 1741; **PV = photovoltaic; D(O) = optional diversion; HW = hydro & wind turbine; L: load control; D: diversion

optimum match between the array and battery bank. MPPT is able to trade volts for amps and vice versa (see the MPPT sidebar). Under some conditions, such as cold weather, overcast days, or low-horizon sunlight, energy gains of up to 35% are possible.

MidNite Solar Classic

MPPT controllers have another big advantage of allowing higher-voltage PV arrays, which operate more efficiently and require smaller wire sizes from the array to the controller. In some cases, especially when the PV array must be located a long distance from the battery bank, the extra cost of MPPT is offset by the savings from being able to use smaller-gauge wire.

Beware of some caveats when choosing between MPPT and non-MPPT controllers. First, all the PV modules (or series strings of modules) feeding an MPPT controller should be identical. Mixing modules from different manufacturers; using different PV technologies (monocrystalline, polycrystalline, or amorphous); or using modules with different voltages and different power ratings should be avoided, as MPPT gains can be compromised and mismatched modules could be damaged.

Be careful when sizing series strings of PV modules that feed an MPPT controller. The "maximum open-circuit voltage" listed in the comparison table is just that—if you exceed this voltage, the controller can be permanently damaged. Remember that PV modules produce higher voltages in cold weather, so an array of three 45 V modules in series for 135 V might be just fine during the summer for an MPPT controller with a 150 V maximum rating—but could damage the controller when it is cold and sunny.

Extra caution is needed when designing and installing PV systems higher than 48 V. All combiner boxes and circuit breakers must be rated for the maximum system DC voltage, as DC electrical arcs are difficult to extinguish and can cause a fire. Accidental electrical shocks during installation that are merely unpleasant at less than 48 V can be lethal at higher voltages. Hire a professional if you have even the slightest doubt of your ability to install the system safely.

Choosing a Controller

First, limit your choices to controllers that work with your battery bank voltage, which will usually be 12, 24, or 48 V. Then, calculate the approximate maximum amperage your

Modes**	Type	Display	Optional Remote	Temp. Comp.	Comm.	Control Relay	Equalize
PV	MPPT	Yes	Yes	Yes	Opt.	Yes	Yes
PV	MPPT	Yes	Yes	Yes	Opt.	Yes	Yes
PV	MPPT	Opt.	Yes	Opt.	No	No	Yes
PV	MPPT	Opt.	Yes	Opt.	No	No	Yes
PV, L	MPPT	Opt.	Yes	Opt.	No	Yes	Yes
PV, HW, D(O)	MPPT	Yes	Yes	Yes	Yes	Yes	Yes
PV, HW, D(O)	MPPT	Yes	Yes	Yes	Yes	Yes	Yes
PV, HW, D(O)	MPPT	Yes	Yes	Yes	Yes	Yes	Yes
PV, HW, D(O)	MPPT	Yes	Yes	Yes	Yes	Yes	Yes
PV	MPPT	Opt.	Yes	Yes	Yes	Yes	Yes
PV	MPPT	Opt.	Yes	Yes	Yes	Yes	Yes
PV, L, D	PWM	Opt.	Yes	Opt.	Yes	No	Yes
PV, L, D	PWM	Opt.	Yes	Opt.	Yes	No	Yes
PV, D	MPPT	Yes	Yes	Opt.	Yes	Yes	Yes
PV, D	MPPT	Yes	Yes	Opt.	Yes	Yes	Yes
PV, L	PWM	No	No	Opt.	No	No	Yes
PV, L, D	PWM	Opt.	Yes	Opt.	No	No	Yes
PV, L, D	PWM	Opt.	Yes	Opt.	No	No	Yes
PV, L, D	PWM	Opt.	Yes	Opt.	No	No	Yes
PV	MPPT	Yes	Yes	Yes	Yes	Yes	Yes
PV	MPPT	Yes	Yes	Yes	Yes	Yes	Yes

controller will need to handle. Divide the PV array watts by the system voltage to get amperage, then add a 25% safety margin to account for higher irradiance conditions. For example, a 40 A rated controller could possibly handle 480 W of PV into a 12 V battery bank; 960 W into a 24 V bank; and 1,920 W into a 48 V bank. After factoring in the additional 25%, those maximum ratings become 384 W, 768 W, and 1,536 W, respectively.

Be sure to carefully check the charge controller manufacturer's specifications for the maximum recommended array wattage for different battery bank voltages. In the comparison table, maximum amperage is shown for 12 V battery bank charging, as some controllers have different maximum amperage ratings at different system voltages.

Next, decide on a PV array voltage. If you go with a non-MPPT controller, the nominal array voltage must match your nominal battery voltage. If you use a MPPT controller, many manufacturers have a spreadsheet or online calculator pre-loaded with the specifications for many popular PV modules. The calculator will also consider the temperature versus voltage performance of your modules, needed to protect the controller from elevated voltage during cold weather.

If there isn't a string-sizing calculator available, you'll need to use the PV module manufacturer's specifications

Xantrex MPPT 60-150

Xantrex C60

Morningstar TriStar MPPT 60

OutBack FLEXmax 80

sheet (along with your area's record low temperature) to determine how high the module voltage could go during cold weather (see this issue's *Methods*). Use this figure to calculate how many modules you can safely place in series. In the comparison table, the maximum open-circuit voltage (Voc) beyond which controller damage can occur is shown. The PV array voltage recommendations for PWM controllers are shown with an "N" for "nominal" after the voltage—the actual Voc of a "12 V" PV module (for example) will be substantially higher than 12 V. See the "MPPT" sidebar for more details.

Other Features

Digital display. It can be handy to look at the controller to see how the PV array is performing, what stage of charging the controller is using, and what the battery bank voltage is. Many charge controllers suitable for the typical home PV array have digital displays, but charge controllers intended for smaller PV systems might not.

Remote metering. Instead of trekking to the controller location to check performance, some have optional remote displays that can be mounted anywhere that's convenient, using inexpensive cable to connect to the controller.

MAXIMUM POWER POINT TRACKING (MPPT)

MPPT has in many ways revolutionized the PV industry. Higher-voltage PV arrays can now be used, reducing wire cost, improving efficiency, and increasing array performance under less-than-ideal conditions (clouds, low-horizon sunlight). But what exactly *is* MPPT, and how does it work?

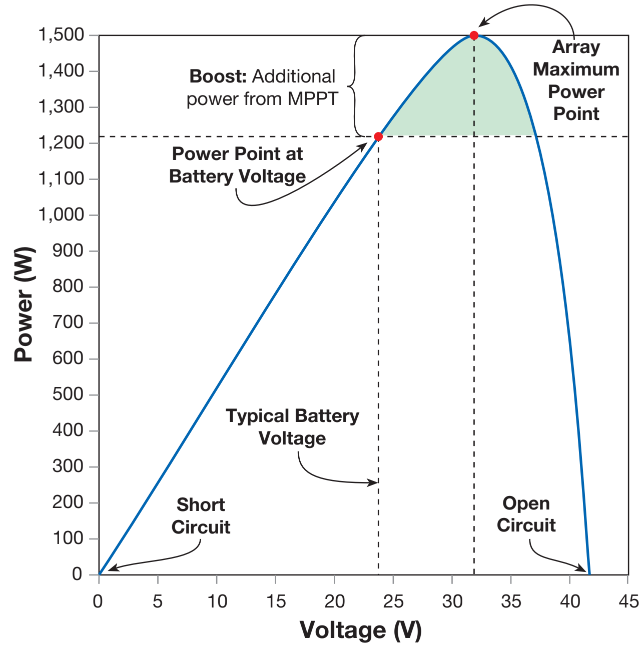
Take a 12 V PV module, put it out in the sun, and measure the open-circuit voltage (Voc)—it will be much higher than 12 V, likely approaching 20 V. The reason that "12 V" nominal modules need to produce more than 12 V is that its voltage is the electrical "pressure" in a circuit, and has to be higher than the battery voltage to "push" energy into those batteries. PV modules perform best at cold temperatures, but their voltage will decrease as they get warmer—by about 0.5% per degree centigrade. A "12 V" nominal battery will rise to more than 14 V as the batteries approach a full state of charge. Higher PV voltage is essential, especially in hot weather; to push amps into the battery.

But what happens to excess voltage, especially in cold weather? Without MPPT, the battery bank "clamps" the array voltage to just above battery voltage, and those extra volts aren't used to produce power.

To extract this extra power, a MPPT circuit will monitor the incoming power and alter the resistance (load) the array sees until it finds the array's MPP voltage. While the MPPT circuit keeps the array operating at its maximum power point, it then uses a DC-to-DC converter circuit to lower the output voltage (and increase the output amps) to the battery bank.

The "MPPT vs. Non-MPPT" graph shows that the output of an MPPT controller operates at the "knee" of the I-V curve—at the maximum power point. As sunlight intensity, array voltage, and battery bank voltage change throughout the day, the MPPT controller automatically readjusts to put the maximum current into the batteries.

MPPT VS. NON-MPPT



Array Rated Wattage: 1,800 W
Array Nominal Voltage: 24 V
Battery Nominal Voltage: 24 V

Remote temperature sensor. Batteries vary in their charging performance depending on temperature data, so a controller can use battery temperature to adjust charging. But because a controller should *never* be mounted inside a battery enclosure, remote temperature sensors are available for some controllers. These sensors are required for *each* controller if multiple charge controllers are used.

Blue Sky IPN Pro Remote meter

Communications options. Many RE system owners like to collect and display performance data from their systems. The ease of data logging and use varies widely between manufacturers and models. Some controllers are LAN-ready and can be monitored via your home network, while others can communicate only to other balance-of-system components (for example, inverters and remote meter panels) made by the same manufacturer. Some give you only RS-232 raw data communications, leaving you to interface the controller with your computer.

Control relays. A charge controller that can perform other tasks based on battery voltage can be useful. It can control relays for battery bank vent fans that turn on only when the batteries are gassing, and automatic generator starting. The control relays will be able to handle only very small loads—larger loads may require a separate, higher-power external relay triggered by the small internal one.

Equalization. If your batteries require regular equalization, some PV controllers allow you to equalize using solar electricity on a sunny day, instead of burning fuel in an engine generator. Scheduled automatic equalizations are available with some controllers. But these should be enabled only with caution—each battery cell's electrolyte level *must* be checked before starting an equalization cycle. And if your batteries can be damaged by equalization (for example, as many sealed lead-acid batteries can), check and double-check that this feature is disabled. Also, be aware that some PV arrays cannot deliver the amps necessary to fully equalize a battery bank, so generator or grid charging may still be necessary.

Access

Author and educator Dan Fink (danfink@buckville.com) has lived 11 miles off the grid in the northern Colorado mountains since 1991. He teaches about off-grid systems and small wind power, and is the executive director of Buckville Energy Consulting, a NABCEP/IREC/ISPQ-accredited continuing education provider. Dan is the coauthor of *Homebrew Wind Power*.

Article 110 of the *NEC*

by Ryan Mayfield

Last issue, we introduced you to Article 110, "Requirements for Electrical Installations," with the encouragement to dig a little deeper into this broad topic. The intention of 110 is to establish some basic ground rules for installation, use, and access to electrical equipment. A good portion of this article concerns itself with the physical space around electrical equipment and adequate, protected access to that equipment.

General Installation Requirements

Section 110.3(B) is one of the most-quoted sections within the *Code*. It requires that equipment be installed in accordance with the manufacturer's instructions. One of the most common violations is PV modules installed on supporting rails that are not at locations specified by the manufacturer. While this is a mechanical specification, not following the manufacturer's instructions can be considered an *NEC* violation. Module manufacturers have determined the maximum distance between the supports that the module can safely span. If the supporting rails are placed too far apart, the module frame may not be able to support the module in a high wind or under snow load.

The next few sections, 110.4 through 110.9, include fundamental information that sets the stage for the rest of the *Code.* Specifically, Section 110.8 stipulates the wiring methods acceptable for all electrical installations. This requires that you cross-reference the specific *Code* sections that cover the wire and raceway type (when applicable) for your installations.

Mechanical Execution

PV installers need to pay special attention to Section 110.12. The language in this section is open to interpretation, as it says, "electrical equipment shall be installed in a neat and workmanlike manner." You will not find a definition of neat or workmanlike in Article 100, but inspectors will know it when they see it. This means you need to keep the wiring from looking like a rat's nest; mount electrical enclosures properly; and route raceways in an orderly fashion. The *Code* includes an informational note in 110.12 that directs you to *Standard Practices for Good Workmanship in Electrical Contracting*, which can help elucidate some of the basic requirements and expectations.

This section has two subsections, 110.12(A), unused openings; and 110.12(B), integrity of electrical equipment and connections. The first is an attempt to keep the integrity of the electrical enclosure equivalent to the original manufacturer's product. For example, if you remove a knockout hole in a box and then decide to not use it, you need to close that hole with an appropriate plug. We all know duct tape is impressive stuff, but this is not an application for it. The second subsection is intended to keep the internal portions of electrical equipment free of damage and contamination (such as paint, plaster, or corrosive residues). This is for safety and proper operation of the equipment.

Keeping Equipment Cool

Keeping PV equipment—particularly inverters—cool can be a very important part of the installation. Some inverters use active cooling (fans), while others use passive methods (natural air flow across cooling fins). In either case, Section 110.13(B) must be taken into account. Having adequate air circulation is imperative. If the configuration of the room or equipment constricts the airflow, then the inverter will not be properly cooled. Inverter manufacturers will also outline the requirements for proper clearances around the inverter, which you will need to follow.

Terminations

Section 110.14 governs electrical connections, such as when conductors are placed in terminals within inverters and disconnects. The first part of this section deals with the longevity of the conductors and termination methods. If dissimilar metals are placed in electrical contact with each other, such as copper with aluminum, a galvanic reaction can cause corrosion, resulting in a high resistance connection. This is exactly what section 110.14 is trying to avoid. Therefore, all terminals used must be identified and listed as compatible with the conductor type. When splicing conductors, the *Code* does not allow dissimilar metals to be in contact with each other, unless the splicing device is identified for the purpose and conditions of use. As a best practice, many installers avoid intermixing dissimilar metals altogether.

In 2011, a new sentence was added to this section, with specific requirements for connectors and terminals used in conjunction with finely stranded conductors. This is similar to the language in 690.31(F) that was added in 2008. The use of finely stranded cables, common for large conductors used

to connect batteries, can be problematic for some terminals. If the terminals were not designed for use with such cables, they may not maintain the proper mechanical and electrical connection over time. The terminal may loosen, creating a high resistance connection. If the resistance becomes too great, this can result in the failure of the terminal and possibly start a fire.

Section 110.14(C) covers temperature limitations for conductors and their associated terminations. Just as conductors are reduced in their ability to carry current in high temperatures, the same is true for the terminations. The terminals carry temperature ratings similar to the conductors with the common terminal ratings at 60°C and 75°C. Higher temperature ratings for both terminals and conductors means that they have the ability to carry more current. For example, from the ampacity tables in the *NEC*, a 10 AWG conductor has the ability to carry 30 A when the conductor rating is at 60°C, versus 35 A and 40 A for conductors rated at 75° C and 90°C, respectively. And since the terminals are considered an extension of the conductor, their ampacity values follow suit with the conductors.

In 110.14(C), the *Code* requires that the ampacity of both the conductors and terminals be based on the lowest common denominator at the point of termination. For example, in PV systems, a conductor that has a 90°C temperature rating is commonly terminated into a fuse holder whose terminal is only rated for 75°C. At that point of termination, the 90°C conductor only has the ampacity of a conductor with a 75°C rating, even though the rest of that conductor will be considered to have the ampacity of a 90°C conductor. This limitation must be factored in along with what are considered conditions of use for the conductors.

110.14(C) has two subsections, one of which is the basis for an electrical industry rule that is often applied to terminal temperature ratings. In 110.14(C)(1), the *Code* makes provisions for terminal ratings based on conductor size and equipment ampere ratings. For equipment rated at 100 A or less, or for conductors marked 14 AWG through 1 AWG, the terminal temperature rating is assumed at 60°C, unless it is marked otherwise. For larger equipment and conductors, the assumed temperature rating is 75°C. This is fairly well applied throughout the electrical industry, except for PV systems. Directly applying this section means that you could place a conductor rated at 90°C in a fuse holder rated at less than 100 A, but only get to consider that conductor to have the ampacity value at the 60°C rating at the point of termination.

It's necessary to examine the equipment and verify the temperature ratings of the terminals, especially for equipment rated less than 100 A. For the most part, the equipment manufactured specifically for the PV industry will use terminals listed at the higher 75°C temperature rating. Some PV equipment manufacturers include 90°C rated terminals as part of their assemblies. However, if a terminal is connected to a device such as a circuit breaker or a fuse holder, the 90°C rating cannot be used. If there is such a device connected to the terminal, then you are limited to the rating of that device. That rating is based on the device's ampere rating or specific markings. For PV-specific equipment, this is typically, but not universally, 75°C. Be especially aware when using standard electrical components—AC load centers and disconnects, for example. If the manufacturer doesn't list their terminal temperature rating, you need to apply 110.14(C)(1) as appropriate.

Making Space

Section 110.26 covers spaces around electrical equipment—working, clear spaces, entrance, egress, and dedicated equipment space. Maintaining all of these requirements can be difficult, since frequently, PV systems are installed in existing buildings and the PV equipment space requirements weren't an original building design consideration.

In general, you can view the first subsection—working spaces—as a cube of unobstructed space that must be maintained around the equipment. This generally requires a minimum of three ft. depth, 30 in. width, and 6.5 ft. height, starting at the floor. Several conditions can call for an increase in those minimums. For example, the working space width must be equal to the width of the equipment *and* allow all hinged doors the ability to open 90° for access to the interior. The dedicated equipment space subsection dictates what is allowable for other equipment surrounding the electrical equipment. (The *NEC Handbook* provides helpful illustrations for all of these working space requirements, clarifying what is and isn't allowed, and also providing helpful explanations on the rest of the *Code*.)

Finally, Section 110.28 covers the types and ratings of enclosures. Table 110.28 outlines the different enclosure type ratings and the associated level of protection from the elements. If you are not familiar with these ratings and the protection levels they offer, this table is worth examining.

Bringing it Together

A firm understanding and confidence level with Article 110 is important for anyone installing PV systems. Spend some quality time with your *Code* book and possibly some additional references to bolster your knowledge of this article.

Access

Ryan Mayfield (ryan@renewableassociates.com) is the principal at a design, consulting, and educational firm with a focus on PV systems in Corvallis, Oregon. He is an ISPQ Affiliated Master Trainer, and really does enjoy reading other books besides the *NEC*.

Ketto Kids

by Kathleen Jarschke-Schultze

Being in the solar design and installation business, my husband Bob-O and I noticed a trend with our customers. In the spring, people tend not to think about installing solar until the sun comes out in earnest. In the autumn, people tend to think about the system maintenance or upgrade they were going get done before winter sets in. So our vacation is always in the dead of winter.

For our tenth anniversary, we applied for and received passports. It would be six years before we actually used them to travel abroad. Years ago, we decided to vacation where the weather was warm in winter. We are not alone in this. It is the big season for travel to tropical climes. For the winter of 2008, we chose Jamaica as our first foreign destination.

Passing It On

Before we travel, we do a lot of research about where we will be. We buy guidebooks and scour the Internet for all the information we can amass before leaving. At one point, Bob-O told me about a yoga center on the Jamaican coast that had a community kitchen so I could prepare all our meals there. I explained to him that a vacation was when you didn't do the chores you usually did every day. We chose an all-inclusive resort in the same neighborhood.

In our online investigations, we read that travelers sometimes packed a few school supplies and donated them to Jamaican schools when they arrived. We thought this sounded swell, so we picked up 15 boxes of crayons and some addition and subtraction flash cards. They did not take up much room and we figured we would find a school while we were in Jamaica.

Upon arriving at the resort, we were guided to our room by Mike, our bellman. He was friendly and talkative, so we asked him about finding a school to visit. Mike shook his head: "This is what you want to do on your vacation?" We assured him that it was, indeed. He told us that one of his childhood friends was married to a woman who ran a small preschool in a small mountain area called Ketto.

We agreed to go with Mike, who drives his car as a taxi on his one day off, to the Ketto Early Childhood Institute on Mike's next day off. Mike would call Lorraine, the preschool teacher, and let her know we were coming.

The School

The day came and we set off with our small bag of supplies. We passed through town and out into the country. Forty-five minutes later, we passed the Ketto post office—a 5- by 6-foot shed set on a slightly larger cement slab. That was "town." A man walked by with a goat on a tether.

A short way up the road, we came to a small church behind a rusted wrought-iron gate. Behind the church was the school. It was one large room divided by blackboards. There was a classroom area for each age group—three-, four-, and five-year-olds. Beyond the school building, a bare dirt yard was separated from the jungle by a rusted barbed wire fence in disrepair. This was the children's playground.

Lorraine was a cheerful woman who welcomed us warmly. She gratefully accepted the crayons as the children danced around excitedly. I asked her for a list of supplies she could use and told her I would send them along when we got home.

Kathleen Jarschke-Schultze

Shiny, happy faces at the Ketto Early Childhood Institute in Jamaica.

Bob-O Schultze

Kathleen with the schoolchildren.

"Can you buy us a fence?" she asked. I told her, no, that was too much money. I wanted to send school supplies. She wrote out a list. One of the items listed was "books," so I asked what kind of books. One of the children brought me their one book—a torn, stained, raggedy copy of *The Pokey Little Puppy.*

Soon we were saying good-bye and promising to send packages. Throughout the next year, I sent several packages of the school supplies Lorraine had asked for, all the while gathering a variety of educational supplies to take with us when we returned the next winter.

The next year when Mike drove us into the hills to Ketto, we had two large suitcases full of assorted supplies, backpacks, books, paints, toys, and musical instruments. Lorraine was ecstatic and the children were round-eyed at the largess.

Lorraine and two other teachers grouped the kids outside, where the whole school sang to us. They sang about Nanny of the Maroons, a runaway slave who founded her own community. The story is that the redcoats shot at Nanny but she just caught the bullets in her hand and threw them back at the soldiers. I knew the kids were singing their history for us. It was wonderful.

We realized we could afford more supplies if we didn't mail them, but hand-carried them in our luggage. The next year, along with the regular supplies, we gave Lorraine Bob-O's old iBook laptop and a color printer. Lorraine had to use them at the church in front of the school where there was an electrical outlet. In the school, one wire supplies the electricity to run the ceiling lights, but there are no outlets.

Fence Fund

My friend Dave, who works at Big Springs Elementary, a small country school in northern California, started his eighth-grade students saving school supplies for the Ketto kids. This meant even more suitcases, now with our clothes and the school supplies strategically packed so that each suitcase would not exceed the 50-pound limit. I have become skilled in the art of Tetris-like packing.

Two years ago, the Big Springs school kids collected $76, and Dave and his wife donated $100 for the Ketto Fence Fund. Bob-O and I rounded the sum out to $1,000 and hand-delivered it, along with the supplies, to Lorraine. She almost cried with happiness. When we arrived last year with our full-to-bursting suitcases, Lorraine excitedly took us around back to the bare playground. There was a nice secure chain-link fence circling the yard with the jungle beyond. "We are so happy now," Lorraine said. "The children are safe."

We surprised Lorraine with a digital camera to use with her computer and printer/copier. In Ketto, Bob-O is usually busy teaching Lorraine to use whatever technology we have brought and I take over Lorraine's class, the three-year-olds. On our visit last year, the kids were fascinated with my long, straight hair. "You're pretty," the little girls said, "but you need braids and beads in your hair."

We have visited the school four winters, now, and are going back again this winter—every year, we look forward to seeing Lorraine and the kids. Our small bit of charity makes us feel better while we vacation in a very poor country. Jamaica has a tourist economy, but we like to think we have grown beyond that role. Oh, and now I'm hooked on Jamaican-style jerk chicken.

Access

Kathleen Jarschke-Schultze (kathleen.jarschke-schultze@homepower.com) is probably sunning on a warm beach rather than cooling her heels at her off-grid home in northernmost California.

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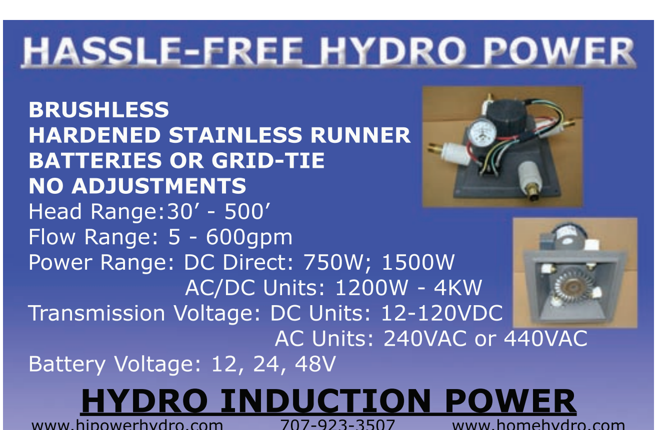
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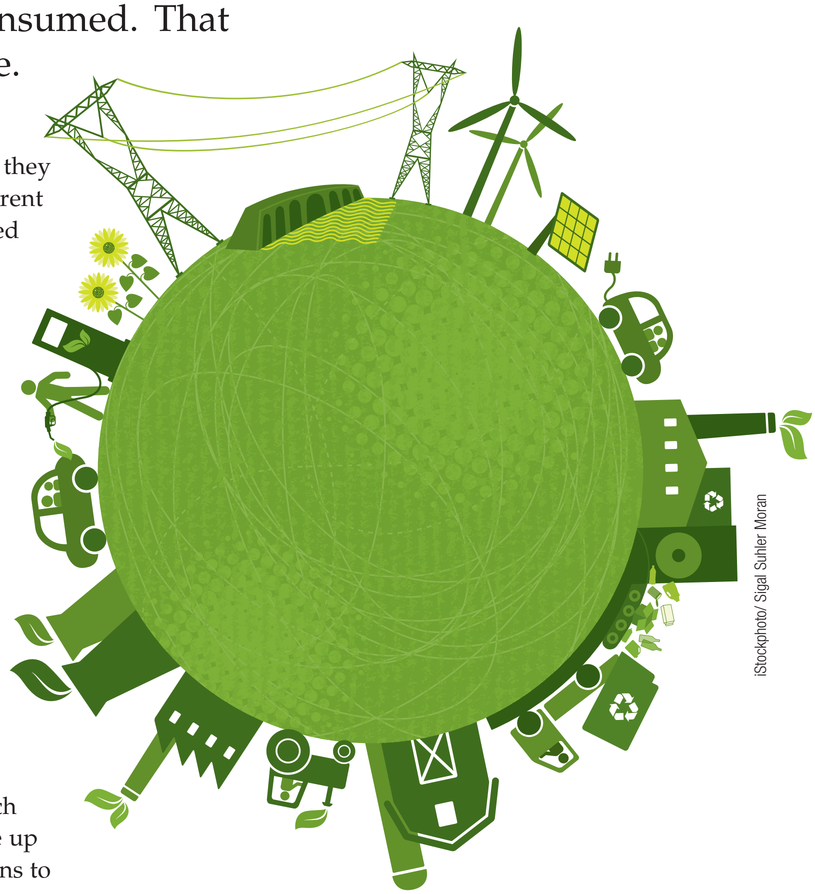
Accounting for Zero

You can't achieve net zero-energy for your house until you know the *total* energy consumed. That means including all the fuels you use.



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There are many ways to get to net zero-energy, but they all require accounting for *all* of your loads. Since different energy sources use different counting units, they need to be converted into a useful standard. It is most convenient to convert to kWh, because most net zero-energy homes use RE-made electricity to offset their total energy use.

I used to say that my family has an "all-electric" house, but that's not really true. When you get down to brass tacks, I can count no fewer than five energy sources that our house uses to power its various appliances and functions. Our house is solar-, electricity- (generated primarily from coal and hydro where I live), and biomass-fueled (plus diesel and gasoline, if you include the vehicles that get us to and from it).

Our water heating and pumping, refrigeration, cooktop and oven, refrigerator, chest freezer, and washer and dryer are electric. In the summer, that makes energy calculations fairly straightforward—all I have to do is look at our electric bill to know how much total energy we've used. But in the winter, when we fire up the wood heater, I have to do some additional calculations to account for our total energy use.

There are some simple conversion figures that can help you calculate your home's total energy use. This is especially important to factor in when you're sizing a PV system to offset your total household loads.

Annually, our household consumes about 7,800 kWh of electricity—about 650 kWh monthly. But we also burn about 3/4 of a cord of seasoned madrone hardwood during the six-month heating season. (Madrone makes excellent firewood; each cord has the energy equivalent of about 30 mBtu).

kWh Conversions

Fuel	Unit	kWh Conversion Factor
Natural gas	1 Therm	29.3
Hardwood (madrone)	1 Cord	8,792.0
Softwood (white pine)	1 Cord	4,103.0
Propane	1 Gallon	26.8
Fuel oil, No. 2	1 Gallon	40.7

Granted, wood is a potentially renewable resource if managed effectively, but besides net *zero-energy*, I'm interested in offsetting our home's carbon emissions. Using the conversion table, we can convert Btu to kWh:

30 mBtu/cord × 0.75/cord × 1 kWh/3,412 Btu = 6,594 kWh

Adding that to our other energy usage:

7,800 kWh + 6,594 kWh = 14,394 kWh

According to NREL's PVWatts, at our location in southern Oregon, we'd need an 11 kW grid-tied PV system to offset all of our household energy usage, including the heating load. That's a pretty big system, and an opportunity to look more closely for where we can tighten our energy belts and conserve energy.

—Claire Anderson